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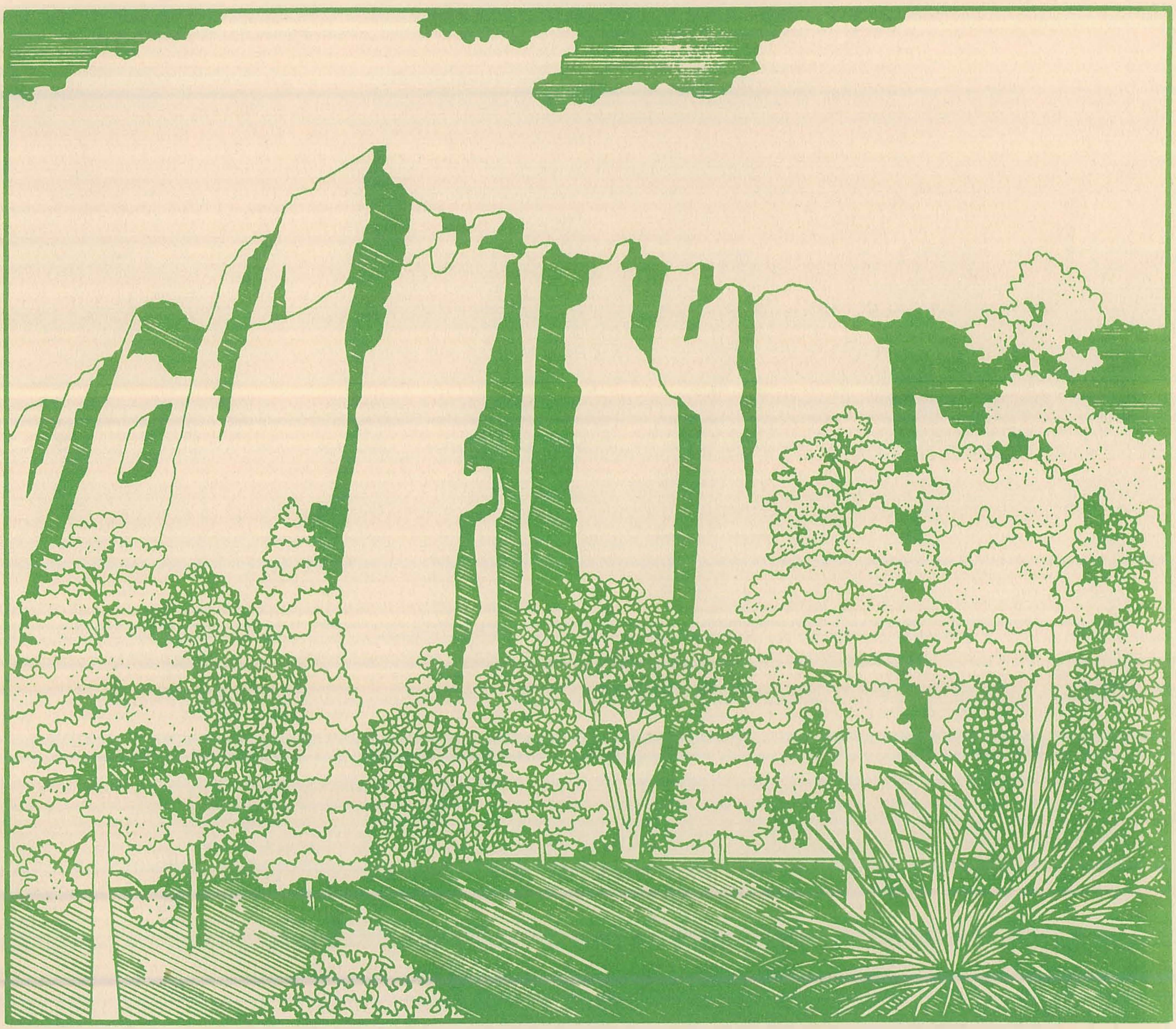
R-3 86-2

RADIAL GROWTH LOSSES IN DOUGLAS-FIR AND WHITE FIR CAUSED BY WESTERN SPRUCE BUDWORM IN NORTHERN NEW MEXICO: 1700 TO 1983

October 31, 1985



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RADIAL GROWTH LOSSES IN DOUGLAS-FIR AND WHITE FIR CAUSED BY WESTERN SPRUCE BUDWORM IN NORTHERN NEW MEXICO: 1700 TO 1983

FINAL REPORT

CONTRACT ON 43-8371-4-628

October 31, 1985

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EXECUTIVE SUMMARY

Dendrochronological analysis of 306 Douglas-fir and white fir trees from the Carson National Forest, New Mexico has produced information on the occurrence, duration, and severity of spruce budworm outbreaks for the past 284 years (1700-1983). Specific findings of this study are summarized below.

1. Absent Rings. Crossdating of the ring width series revealed that less than one percent of all rings in the host tree samples were locally absent on the sampled radii, however, the majority of these growth anomalies occurred during identified budworm outbreaks. Growth loss estimates would probably have been significantly underestimated if these absent rings had not been identified.

2. Occurrence and Timing of Outbreaks. Three documented outbreaks that occurred after 1920, including the current outbreak, were recorded in the tree-ring series. At least five different periods of low growth before 1920 were inferred to be past budworm outbreaks affecting 2 or more of the study areas. The timing of identified outbreak periods tended to agree between study areas, especially for those areas on the eastern side of the Rio Grande, indicating that the infestations were usually wide-spread.

3. Intervals Between Outbreaks. The average interval between the last year of the previous outbreak and the first year of the next outbreak was 19.7 years; the average interval between first years of the outbreaks was 32.8 years. The variation of these intervals was quite high, therefore these statistics are not particularly useful for predictive purposes.

4. Duration of Outbreaks. The average number of years in all identified periods was 14.0, and the periods varied in length from 6 to 26 years. The duration of outbreaks in northern New Mexico appear to be longer than estimates for the northern Rocky Mountains.

5. Severity of Outbreaks. The average maximum one year growth loss for all identified outbreaks was 42.5%, and the average periodic growth loss was 19.0%. No obvious trend of increasing or decreasing severity was noted, however, certain outbreaks were evidently more severe than others. For example, the growth loss estimates for an outbreak that occurred from approximately 1885 to 1910 are relatively high in two study areas, and evidence of a growth release following this period indicates that there was some mortality in these stands. There are some indications that the current outbreak is more severe than average.

6. <u>White Fir and Douglas-Fir Growth Loss Comparison</u>. The average maximum one year growth loss in all host trees for the past three outbreaks was approximately 57.0%. The average periodic growth loss was 22.8%. Results of the comparison of white fir growth losses with Douglas-fir growth losses were somewhat mixed, partly because only three outbreak periods could be compared, one of which is the ongoing current outbreak. Two of the periodic growth loss comparisons indicated that white fir losses were significantly greater (approximately 14%) than Douglas-fir losses.

7. <u>Age Class Growth Loss Comparison.</u> Douglas-fir trees within each study area were found to cluster in two or three age classes that generally correspond to the sawtimber and pole size classes. Only 5 of the 23 comparisons of growth loss were significantly different, with the older age class showing greater losses than the younger in 4 of these 5 comparisons. The older age class sustained an average of approximately 7% greater maximum one year growth loss and 4% greater periodic growth loss than the younger age class.

8. <u>Correlation of Defoliation, Insect Populations, and Radial Growth.</u> Correlation of tree defoliation data and radial growth measurements grouped by year were generally low but significant. The correlations changed through time, probably because of a combination of individual tree defoliation history, lag effects, and climatic influences on tree growth. Correlation of average block defoliation with average block radial growth were much higher. Current years defoliation and cumulative defoliation correlated highest with radial growth. Correlation of insect population parameters and radial growth were also highly significant, especially egg mass densities for the previous year.

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INTRODUCTION

Regional outbreaks of western spruce budworms (*Choristoneura occidentalis* Freeman) have recurred at least three times in northern New Mexico since the early 1920's when the U. S. Forest Service first began systematic forest pest surveys and documentation (Lessard 1975, U. S. Forest Service documents). The current outbreak was first noticed in a small area on the Taos Indian Reservation in 1974, and since then the defoliated areas have increased in New Mexico and Arizona to more than 370,000 acres of Federal, Indian, State and private lands (Linnane 1984).

Losses in timber values can generally be ascribed to radial growth loss, height growth loss, topkilling, reduced regeneration, and mortality (Carlson *et al*. 1983, Fellin *et al*. 1983). A damage assessment project was initiated in 1978 and was aimed at obtaining measurements of some of these losses in budworm infested stands on the Carson National Forest, New Mexico (Holland and Lessard 1979). A large data base has subsequently been developed, including yearly measurements on topkilling, mortality, defoliation, and insect population changes (Stein 1980, 1981, Stein and McDonnell 1982, Rogers 1984).

A growth assessment study was undertaken in 1982 to determine the feasibility of using dendrochronological methods to identify the timing of past outbreaks and to quantify radial growth losses associated with budworm defoliation (Swetnam 1984). Results of this work showed that three major outbreaks during the twentieth century were clearly visible in the tree-ring samples obtained from currently infested trees. The radial growth of host trees was corrected for age, climate and other non-budworm environmental effects, and then growth losses were computed as a percentage of expected growth (Swetnam 1984).

Additional collections were obtained in 1984 in order to expand the scope of the radial growth study. The objectives included 1) assessment of a larger number of tree-ring samples, 2) comparison of radial growth losses between the two primary host species - Douglas-fir (*Pseudotsuga menziesii*) and white fir (*Abies concolor*), 3) comparison of radial growth losses between age classes, and 4) analysis of the relationship between yearly measurements of defoliation, insect populations and radial growth. This report summarizes the findings of the above analyses. Increment core samples from the 1982 collections are included here, therefore this report supersedes the earlier report (Swetnam 1984).

Information is also presented on observations derived from the dated tree-ring series on the timing of occurrence of known and inferred spruce budworm outbreaks for the past 284 years (1700-1983). This is the longest record of spruce budworm occurrence yet developed for western North America.

METHODS

Study Area

The damage assessment project initiated by the Southwestern Region, Forest Pest Management, in 1978 originally included 12 one-acre study blocks within budworm infested stands on the Carson National Forest (Stein 1980, 1981). These blocks were chosen as representative of various mixed conifer stand types and conditions observed in the infested area. Five additional uninfested blocks were established in 1979 as controls; however, these blocks also became infested later in 1979 and 1980. All 17 of the blocks were examined by the author in the summer of 1982, and a subset of 11 blocks were chosen for sampling and dendrochronological analysis.

Figure 1 shows the location of the study areas sampled in 1982 and 1984. The study areas (indicated by the 3 letter codes in Figure 1) included one or more of the one-acre blocks originally established by the Forest Service. Description of the tree species composition and stocking of the individual blocks are given in Table 1. Elevations range from approximately 2,438 meters (7,900 feet) to 3,050 meters (10,000 feet). Annual precipitation for the study areas is approximately 64 to 76 centimeters (25-30 inches)(Beck and Haase 1969).

Sampling Strategy

Dendrochronological principles were used in selecting the eleven blocks included in the study (Fritts 1976, LaMarche 1982). The basic criteria used in this selection was moisture regime, slope, aspect, and the availability of non-host species within or near the selected blocks. Those blocks that appeared to be relatively mesic and poorly drained were eliminated from the sampling scheme because it is known that, in this region, trees growing in these conditions, and at these elevations, typically have a very low response to year-to-year climatic changes (Fritts 1974). Tree-ring series from these sites would exhibit very little year-to-year variation in ring width, which is essential for crossdating (pattern matching of ring-width sequences within and between trees). Crossdating is a necessary step in tree-ring analysis because of the possibility of growth anomalies such as double rings or locally absent rings (Douglass 1941). The chances for locally absent rings are much higher in trees that have been stressed by insect outbreaks (Evenden 1940, O'Neil 1963, Swetnam 1984).

Figure 1. Carson National Forest, New Mexico. Study areas are indicated by three-letter codes: BRN = Burned Mountain, block 17; CAB = Cabresto Canyon, blocks 11 and 12; CPN = Capulin Canyon, blocks 5 and 6; GAR = Garcia Park, blocks 2 and 7; OSH = Osha Mountain, blocks 13, 14, 15 and 16.

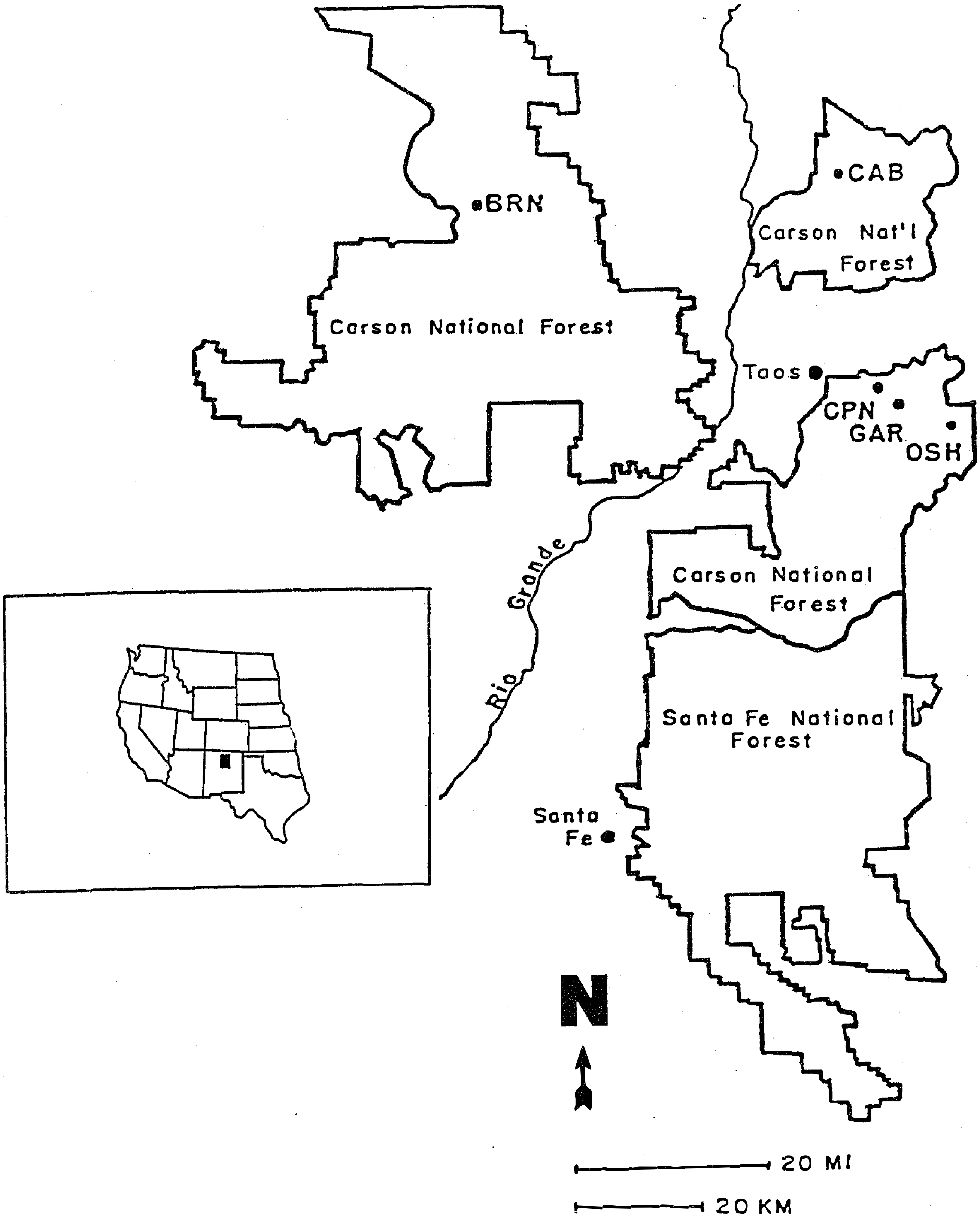


Table 1. Species composition and stocking of study areas. PSME = *Pseudotsuga menziesii*, PIPO = *Pinus ponderosa*, PIEN = *Picea engelmannii*, ABCO = *Abies concolor*. Data from Rogers (1984).

Study Area Block No.	Species Composition % PSME	PIPO	PIEN	ABCO	Size Class %[1] Pole	Saw-Timber	Trees PerAcre
Capulin Canyon							
5	29.6	59.2	0.0	11.3	18.3	81.7	72
6	44.6	21.5	0.0	33.8	43.1	56.9	66
Garcia Park							
2	87.7	5.3	0.4	6.6	60.8	39.2	230
7	82.4	15.2	0.0	2.4	62.8	37.2	252
Osha Mountain							
13	93.9	0.0	1.8	4.9	71.8	28.2	163
14	43.6	24.6	2.1	29.7	60.5	39.5	188
15	62.7	0.0	31.1	6.2	48.6	51.4	177
16	7.6	0.0	75.3	17.1*	79.7	20.3	327
Burned Mountain							
17	81.7	0.0	10.9	7.4	52.0	48.0	204
Cabresto Canyon							
11	66.4	0.8	17.2	15.6	66.4	33.6	128
12	69.0	0.0	28.1	2.9	71.9	28.1	172

[1] Trees with a d.b.h. of 5.0 to 8.9 inches were classed as poles, while those with a d.b.h. of 9.0 inches or larger were classed as sawtimber.

* *Abies lasciocarpa*.

Twenty to twenty-five Douglas-fir trees in each block were monitored by Forest Pest Management personnel from 1978 or 1979 to 1983 for defoliation and insect populations (Stein 1980, Rogers 1984). These trees were sampled in 1984 by taking two increment cores per tree from the lower bole between approximately 1.0 and 1.4 meters (3-4.5 feet) above the ground. The monitored trees were selected by Forest Pest Management personnel on a more-or-less random basis from all trees that were between 6 and 12 meters (20-40 feet) in height. Thus, the monitored trees are relatively young (generally less than 100 years old) with diameter at breast height (1.37 meters) less than approximately 25 centimeters (10 inches).

Increment cores were also taken from 5 to 15 additional Douglas-fir trees within and near each block. These trees were selected as the oldest appearing trees in the general vicinity. This selection strategy was intended to obtain the longest tree-ring records available from the site, as well as to obtain a sample of older trees for growth loss estimation.

An additional 26 pole size or larger white fir trees were randomly sampled within block number 6 at Capulin Canyon. Twenty-five and 26 pole size or larger white fir trees respectively were sampled at sites near Garcia Park and Burned Mountain (blocks 2, 7, and 17). The white fir collections from these areas were obtained from sites of less than 0.5 hectare (1 acre). These collections were not obtained from within the established blocks because the white fir component was not large enough for sampling (Table 1).

Increment cores were also obtained from non-host trees to be used in the radial growth analysis as climate and environmental controls. Two cores were obtained from each of 14 to 22 ponderosa pine (*Pinus ponderosa*) trees at the Capulin Canyon, Garcia Park, Burned Mountain and Osha Mountain sites. Seventeen piñon (*Pinus edulis*) trees were cored at the Cabresto Canyon site. The non-host collection at Capulin was partly from within block number 6, while all other collections were from nearby areas (within 2 kilometers) that were composed of nearly pure stands of the non-host species.

Table 2 lists the number of trees sampled by block and species. A total of 464 host and non-host trees were sampled, while the final data sets include a total of 413 trees. The final data sets include only those samples that could be successfully carried through the standardization procedure described in the next section. A total of 306 host trees were included in the growth loss and correlation analysis. The reasons for eliminating some samples and collections at various stages in the analysis are discussed in the results section.

Table 2. Number of increment cores and trees sampled and analyzed by study area and species.

Study Area Species	Sampled Cores	Sampled Trees	Analyzed[1] Cores	Analyzed[1] Trees
Capulin Canyon				
PSME	122	61	113	60
ABCO	52	26	50	25
PIPO	29	14	26	13
Garcia Park				
PSME	98	49	91	48
ABCO	50	25	50	25
PIPO	28	14	24	12
Osha Mountain				
PSME	234	117	221	106
PIPO	41	20	31	16
Burned Mountain				
PSME	98	49	90	45
ABCO	54	27	45	22
PIPO	44	22	22	14
Cabresto Canyon				
PSME	46	23	34	17
PIED	34	17	20	10
Totals:	930	464	818	413

[1] Analyzed samples were processed at least through the standardization step and are reported as average index chronologies by study area and species in Appendix A.

Development of Indexed Tree-Ring Chronologies

The radial growth analysis procedures were briefly described in Swetnam (1984) and in more detail in Swetnam _et al_. (1985), therefore only the general steps will be listed here.

(1) The increment core samples were carefully mounted in wooden holders, assuring that all tracheid cells were perpendicular to the working surface. The samples were then sanded to a very fine surface with up to 400 grit sandpaper.

(2) The ring widths of all samples were crossdated by the skeleton plot technique (Stokes and Smiley 1968) to identify false rings (two growth bands formed in one year) and missing rings (years in which no growth layers were formed).

(3) The ring widths were measured on a sliding stage micrometer, and then a subset of the rings were remeasured to test the precision of the measurements and to check for inaccuracies (Fritts 1976).

(4) A further check of dating accuracy and measurements was conducted by analyzing the statistical crossdating of the series with a computer program designed for that purpose (Holmes 1983).

(5) The tree ring width series were transformed to growth indices (standardization) by fitting curves to the original series and dividing the ring-widths by the values of the curves (Graybill 1979, Cook and Peters 1981).

(6) The host (PSME and ABCO) and non-host (PIPO and PIED) tree-ring series were graphically and statistically compared to determine if the different species were responding similarly to climate (high frequency year-to-year changes), but differently during periods of known budworm defoliation (low frequency, or long term growth changes). If the host and non-host species did not appear to be responding similarly to climate, or if the long term growth trends of the two species were not similar during any periods, then no further analysis was carried out on those series.

(7) The non-host series were used to remove (or to subtract) the climatic or other non-budworm environmental signals from the host series. This resulted in corrected tree-ring indices for all individual host trees, as well as an average corrected index series for each study area (Nash _et al_. 1975, Swetnam _et al_. 1985).

Identification of Known and Inferred Outbreak Periods

The average corrected index series for each study area was examined to determine if periods of low growth during the era of Forest Service documentation (1922 to present) corresponded with known episodes of budworm outbreaks in each area. Similar periods of low growth during earlier years (before 1922) were then identified as probable budworm outbreaks using the following criteria:

(1) Values of the corrected indices were less then 1.00 (expected growth) for five or more consecutive years, <u>and</u>

(2) The lowest growth value during this period was greater than 1.28 standard deviations from the mean of the series ($p < 0.10$, for a one sided z-score significance test).

Periods having both of the above criteria were considered to be probable outbreaks and are referred to as "inferred" budworm outbreaks. Post-1922 periods corresponding to documented outbreaks are referred to as "known" budworm outbreaks.

The criteria used for identifying inferred outbreaks were based on observed characteristics of the indices during the known outbreak periods. These guidelines seemed to provide a reasonable basis for screening out short term periods of low growth that may have been due to random or unexplained variations in the host or non-host series that were unrelated to budworm effects.

Duration in years of all known and inferred budworm outbreaks was computed. The first year of an outbreak was defined as the first year of growth below a corrected index of 1.00, and the last year of an outbreak was defined as the last year of growth below 1.00 preceding two or more years of growth exceeding 1.00. Duration of an outbreak was the interval in years between the first and last years inclusive.

Intervals between identified outbreaks were also computed. These were defined as the interval in years between the last year of a previous outbreak and the first year of the next outbreak. Finally, intervals were computed between the first years of identified outbreak periods.

Computations of Growth Loss

Radial growth losses were computed from both the average corrected index series for each study area (all host trees included) and the corrected index series for each host tree within each study area. The individual host tree growth loss

estimates were computed only for the known budworm outbreaks. Growth loss was defined as the difference of the corrected index value during a year or years and the expected growth for that year or those years. The expected growth in a tree-ring index series is equal to the mean of the series, which is approximately 1.00. Growth loss values were expressed as a percentage by multiplying the differences by 100.

The first growth loss measurement that was computed was the maximum growth loss in a single year during an outbreak period. The second measurement was the average or periodic growth loss for the identified outbreak. The periodic growth loss measurement included a different number of years depending on the block being analyzed and the observed first and last years of the outbreak within that block.

Comparison of Growth Losses Between Host Species and Age Classes

The mean maximum one year growth losses and the mean periodic growth losses of the Douglas-fir and white fir trees were compared to determine if any statistical differences existed. A two-sample t-test (Freese 1967) was used in the analysis.

All of the Douglas-fir trees at each study area were stratified into an "old" and "young" age class based on the observed age structure of the sampled stands. Nearly all of the core samples extended to near the pith, so approximate mean ages of the groups were estimated by averaging the number of rings in the samples and adding 10 years for the trees to reach coring height. Growth losses were computed for each age class and then the t-test was used to determine if differences in the means were significant.

Correlation of Defoliation, Insect Populations, and Radial Growth

A correlation analysis was carried out to study the relationships between the Forest Pest Management measurements of yearly defoliation (% loss of current years foliage growth), insect populations (egg mass densities, and larval densities) and the computed radial growth measures derived from this study. Pearson's product moment correlation coefficients were computed for common periods of data for individual trees and for block averages (Freese 1967). Single variable and stepwise multiple regression (Draper and Smith 1981) was then applied to determine if a suitable and reliable empirical model could be developed for predicting radial growth loss from defoliation and/or insect population data.

RESULTS AND DISCUSSION

Absent Rings

Crossdating of the increment cores revealed that relatively few annual rings were locally absent. For example, only 53 rings were absent among the 14,572 dated rings in the collection of Douglas-fir trees from Garcia Park. This amounts to only 0.36 percent of all rings in this collection. However, these absent rings were distributed among 40 percent of all trees sampled at this site and furthermore, it was later noted that the majority of these locally absent rings (37 rings, or 69%) were during years identified as known or inferred budworm outbreaks. It is therefore evident that if these absent rings had not been discovered then growth loss estimates during the identified outbreaks would have been significantly underestimated.

Another notable aspect of the absent rings was the predominance of these growth anomalies in the years 1980 to 1983. Twenty-four percent of all absent rings in the host trees from all study areas occurred during these years, which was the largest proportion for any outbreak period. Thus, it is possible that the current outbreak is of greater severity than past outbreaks. Further observations on the relative severity of outbreaks will be discussed in a later section concerning growth loss estimates.

A few increment cores could not be dated because of breakage or loss of parts of the cores, or because the crossdating was not apparent. These samples were excluded from further analyses. Some samples were excluded because scars or branches along the radii distorted the growth trends. Increment core samples from a total of 51 host and non-host trees were eliminated for the above reasons, while the remaining 413 trees were successfully dated, measured, standardized and averaged into the indexed study area chronologies. These chronologies, their descriptive statistics, and sample depths are included in Appendix A.

Comparison of Host and Non-host Tree-Ring Series

The tree-ring indices of the host trees were compared with the average non-host series from each study area to determine whether the two species were generally responding to year-to-year

(high frequency) climatic changes in a similar manner. The uppermost plots in Figures 2 and 3 are examples of the comparisons of Douglas-fir (host) and ponderosa pine (non-host) average tree-ring indices from two of the study areas.

The middle plots in Figures 2 and 3 show comparisons of low pass filter values of the host and non-host average chronologies. These values were obtained by smoothing the index series with a digital low pass filter, which removes most of the variations over time periods from 2 to 8 years and preserves most of the low frequency variance (Fritts 1976, LaMarche 1974). The filtered series comparisons de-emphasize the short-term or climate induced fluctuations in common between the host and non-host series while emphasizing the long term growth differences that are more likely to be due to the effects of budworm defoliation (Swetnam _et al_. 1985).

The product moment correlations of all of the host/non-host average tree-ring index comparisons are given in Table 3. All of these comparisons produced strong significant correlations ($p < 0.001$), which is a good indication that the relative year-to-year growth changes in the two series are in agreement. This agreement was also evident in the graphical comparisons (upper plots in Figure 2 and 3). The low pass filter comparisons (middle plots Figures 2 and 3) showed agreement in trend between the two species during some periods, but differences in direction of trend during the known and suspected budworm outbreaks.

The correlation of the Cabresto Canyon Douglas-fir and piñon collections was the highest of all the host/non-host comparisons ($r = 0.715$). The graphical comparisons of these series also showed very good agreement among the index and filtered series with no identifiable periods of Douglas-fir decline in the twentieth century that might have been associated with budworm outbreaks.

The lowest correlation was for the white fir/ponderosa pine comparison from Garcia Park ($r = 0.383$). The filtered series comparison of these series showed very little correspondence in growth trends during any periods. It was therefore determined that the growth response of the two species at Garcia Park were so dissimilar that a valid comparison was not possible, and the white fir series was excluded from the correction procedure and subsequent growth loss estimates. It is suspected that these growth differences were due primarily to site effects rather species differences, because the white fir collection from Garcia Park was from a much more mesic site than the ponderosa pine. Also, the white fir/ponderosa pine comparison from Capulin Canyon, where the two species were sampled from the same stand, indicated a good agreement in relative year-to-year growth changes and in general trends between known outbreak periods.

Figure 2. The average tree-ring index series of ponderosa pine (lines) and Douglas-fir (lines with triangles) from Garcia Park are shown in the top plot. The same series were treated with a low pass filter and are shown in the middle plot. The Douglas-fir index series was corrected by subtracting a rescaled version of the ponderosa pine series, and the resulting corrected indices are shown in the bottom plot. The open arrows show years of known spruce budworm outbreaks, while the arrows with question marks indicate inferred outbreaks. See the text for detailed explanation of methods.

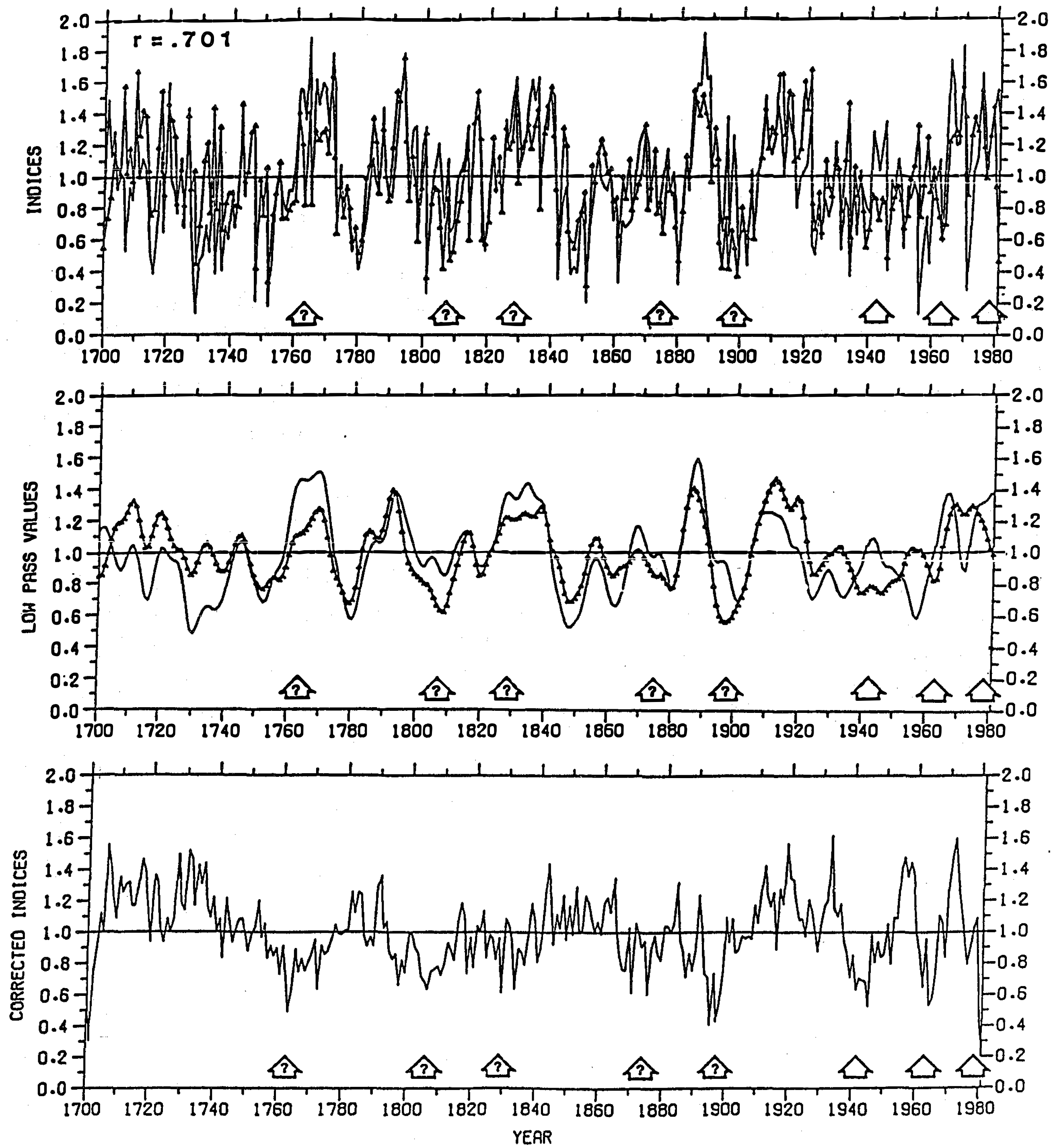


Figure 3. The average tree-ring index series of ponderosa pine (lines) and Douglas-fir (lines with triangles) from Capulin Canyon are shown in the top plot. The same series were treated with a low pass filter and are shown in the middle plot. The Douglas-fir index series was corrected by subtracting a rescaled version of the ponderosa pine series, and the resulting corrected indices are shown in the bottom plot. The open arrows show years of known spruce budworm outbreaks, while the arrows with question marks indicate inferred outbreaks. See the text for detailed explanation of methods.

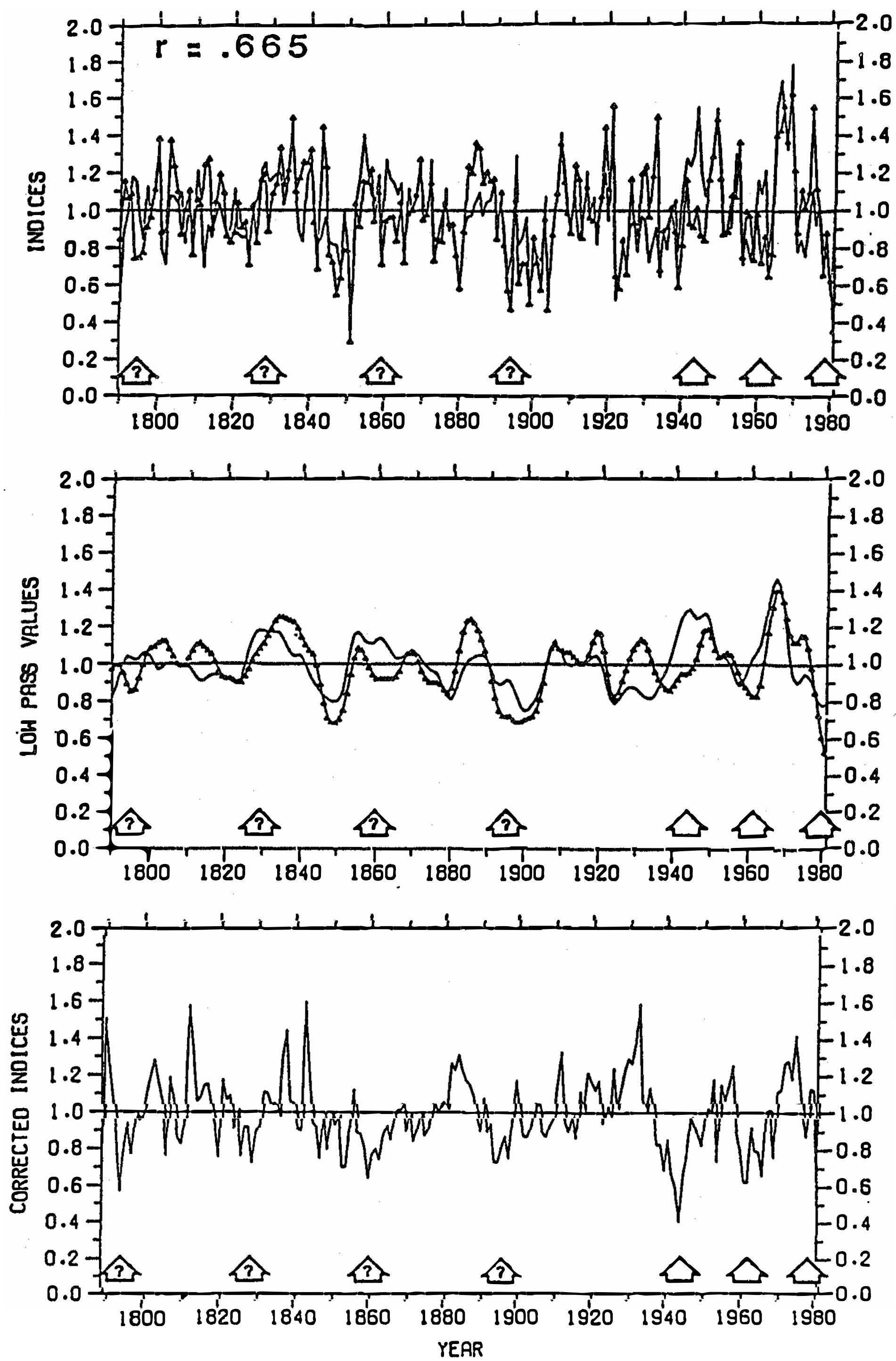


Table 3. Correlations (r) between average index chronologies of different species in each study area. All correlations are significant at $p < 0.001$.

Study Area	Series	Period	Number of Years	r
Capulin Canyon	PIPO & PSME	1790-1981	192	.665
	PIPO & ABCO	1840-1981	142	.580
	PSME & ABCO	1840-1981	142	.847
Garcia Park	PIPO & PSME	1700-1981	282	.701
	PIPO & ABCO	1890-1981	92	.383
	PSME & ABCO	1890-1981	92	.535
Osha Mountain	PIPO & PSME	1700-1981	282	.482
Burned Mountain	PIPO & PSME	1850-1981	132	.554
	PIPO & ABCO	1900-1981	82	.467
	PSME & ABCO	1900-1981	82	.389
Cabresto Canyon	PIPO & PSME	1871-1981	111	.715

The Burned Mountain white fir/ponderosa pine comparison yielded a correlation of 0.467. These collections were also from quite different sites. The white fir were growing through the canopy of a mature aspen stand on a northern exposure, while the ponderosa pine were growing in an open, pure stand approximately 2 kilometers away. The low pass comparison showed a better agreement at the low frequencies than the Garcia Park white fir/ponderosa pine comparison, especially for the period after 1950. However, because the low frequency growth trends of the two species were dissimilar before 1950, a decision was made not to use the corrected indices before this date for growth loss estimation. Consequently, these series were processed through the correction procedure and growth loss estimates were derived only for the current outbreak.

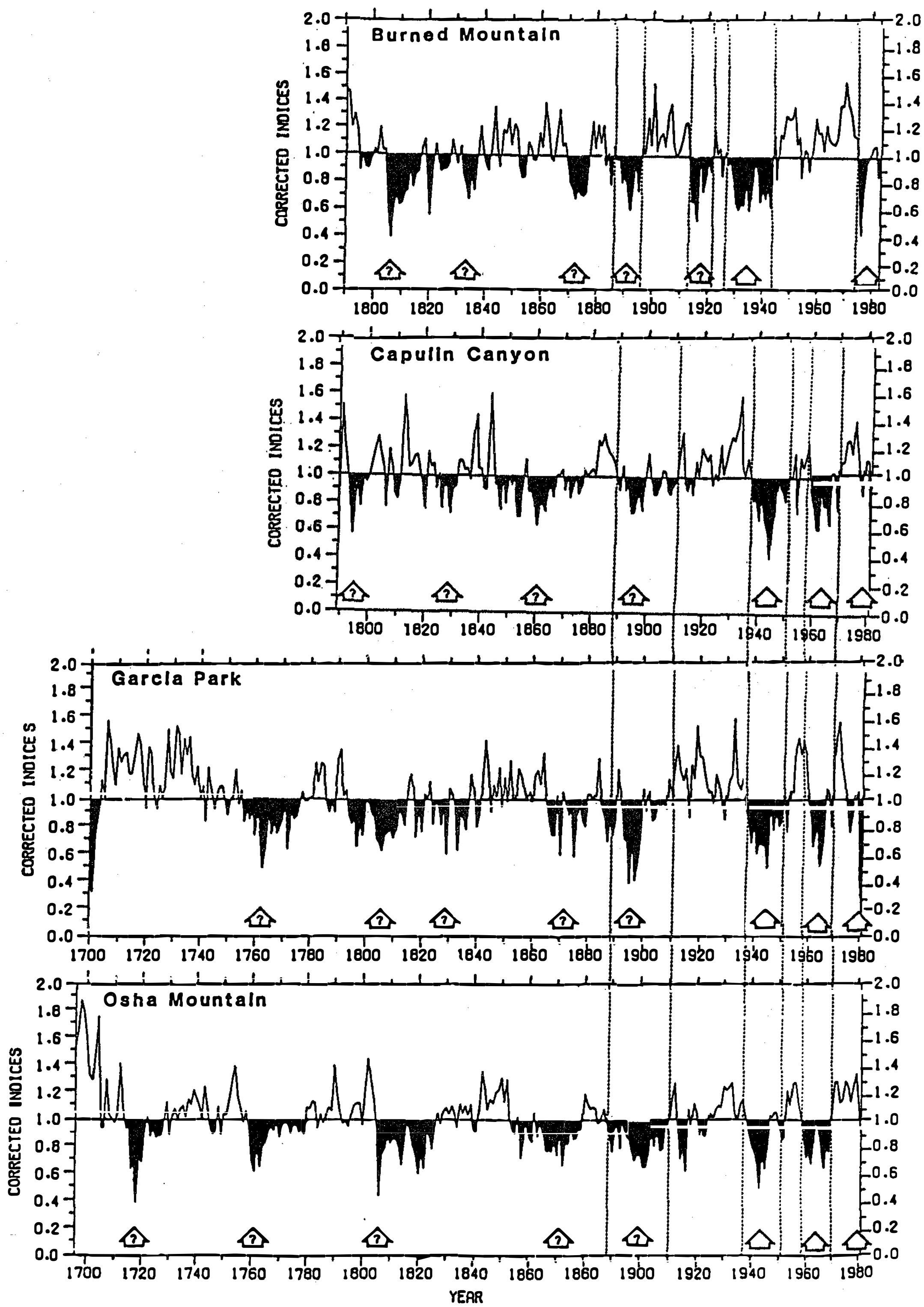
The bottom plots in Figures 2 and 3 show the corrected host indices derived by subtracting a rescaled set of the non-host residuals from the host indices (Nash et al. 1975, Swetnam et al. 1985). The corrected indices distinctly show the periods of known and inferred budworm outbreaks as periods of low corrected index values (see arrows in Figures 2 and 3). The average corrected index series from each of the study areas are included in Appendix B. All of the corrected indices extend to 1981, except the Burned Mountain series which extends to 1983. The non-host species were originally sampled in the summer of 1982 at all sites except the Burned Mountain ponderosa pine which was sampled in the summer of 1984. Thus, the last complete growth rings in the non-host chronologies determined the ending date of the corrected indices.

Occurrence, Duration, and Severity of Recent and Past Outbreaks

Twentieth Century Outbreaks. Examination of all of the corrected index series from individual trees and the average index series from each study area revealed periods of low indices during the twentieth century and earlier. Figure 4 shows the average corrected index series from 259 Douglas-fir trees from four of the study areas. Sample depths of each of these series is included with the chronology listings in Appendix B.

The Cabresto Canyon corrected series is not included in Figure 4. No twentieth century outbreaks could be identified at this site, although a possible outbreak was noted during the late 1800's. However, since this period was represented by only a few trees it was not used in the following analyses. The earlier report on this study (Swetnam 1984) includes plots of the Cabresto Canyon filtered and corrected series, and discusses the findings at this site.

Figure 4. Corrected index series of Douglas-fir trees from four study areas. Blackened periods indicate known and inferred budworm outbreaks. Known outbreaks are shown with open arrows; inferred outbreaks are shown with arrows and question marks. Dotted lines show approximate outbreak periods during the late nineteenth and twentieth centuries.



The dotted lines in Figure 4 indicate periods of known and inferred budworm outbreaks during the late nineteenth and twentieth centuries that appear to have affected the four study areas. Notice the apparent correspondence of the outbreak periods between the study areas on the eastern side of the Rio Grande (bottom 3 plots). These areas are Capulin Canyon (CPN), Garcia Park (GAR), and Osha Mountain (OSH) (see Figure 1). In contrast, the study area on the western side of the Rio Grande, Burned Mountain (BRN), shows different periods of budworm outbreak. Dotted lines are also included on the Burned Mountain plot to illustrate the different timing of the late nineteenth and twentieth century outbreaks.

Note that a budworm outbreak appears in the Burned Mountain series in the 1920's. This conforms to historic documentation of the first recorded occurrence of budworms in New Mexico in 1922 on the western division of the Carson National Forest (Lessard 1975). The available Forest Service documents for the early 1920's to the 1950's are restricted to very short annual summaries of insect damage surveys and generally refer only to conditions on Ranger Districts or to general areas, so it is difficult to precisely identify areas that were infested. Nevertheless, the occurrence of a chronic budworm problem on the western division of the Carson (including the Burned Mountain area) from the 1920's to the 1940's is evident from both the documentation and the corrected indices.

The corrected indices also suggest an earlier outbreak from approximately 1914 to 1921 at the Burned Mountain site. The corrected indices at Capulin Canyon and Osha Mountain also show low growth during this period (Figure 4); however, these periods at these sites do not meet the criteria outlined in the methods section for identifying inferred outbreaks.

The first recorded occurrence of budworm outbreaks on the eastern division of the Carson was in 1940 (Lessard 1975). Other Forest Service documentation verified the timing of the 1940's, 1960's and the current outbreak in Capulin Canyon, Garcia Park and Osha Mountain study areas. It is clear from the records that the peak of the 1940's outbreak was between 1944 and 1946, and that the peak of the 1960's outbreak was between 1960 and 1963 (Lessard 1975). These years correspond very well with the year of maximum growth loss for the eastern division study areas (Figure 4).

The current outbreak is the best documented of all twentieth century outbreaks. The timing of growth decline at the Capulin Canyon, Garcia Park and Osha Mountain study areas seems to be in agreement with the first records of appearance of budworm in these areas in the late 1970's (Rogers 1984). Notice that the Osha Mountain corrected indices decline only in 1980 and 1981, which are the last two years of the series. Budworms were detected in this area in 1979 but defoliation of current years foliage did not exceed 10% until 1980.

Four years of low Douglas-fir growth were recorded at the Burned Mountain site from 1975 to 1978, then growth increased to slightly above normal values from 1979 to 1981. A lower than expected value was measured for 1982. However, this block was originally established as a control in 1979 because it was visually free of infestation, then budworms were detected in this stand in 1980 (Rogers 1984). Thus, the recorded low growth period from 1975 to 1978 is either a record of undetected budworm infestation, or it is an anomalous period of low growth reflecting an unexplained difference in growth between the non-host and host species. It is suspected that this low growth period was indeed a short period of defoliation that may have lasted from about 1975 to 1977, and then for some unknown reason the budworm population declined to an undetectable level in 1978 or 1979. Then in 1980 budworm populations resurged in this particular stand. Evidence that budworm populations were present in the Burned Mountain area throughout the late 1970's is available in the corrected white fir index series from a site approximately 2 kilometers from the Douglas-fir site (see Figure 9, lower plot).

Pre-1900 Outbreaks. The generally good verification of observed low corrected indices with documented outbreaks in the twentieth century provided a basis for inferring that similar low periods in the past were also budworm outbreaks. Table 4 lists the results of using the average Douglas-fir chronologies from each study area (Figure 4 and Appendix B), and the criteria outlined in the methods section, to determine the timing, duration, intervals between outbreaks, and relative severity of outbreaks for the past 284 years (1700-1983).

One notable aspect of the timing of the pre-1900 outbreaks is that there appears to have been some synchroneity of occurrence among the study areas (Figure 4, Table 4). For example, the following approximate inferred periods of budworm outbreak overlap between two or more of the study areas, and some of the years of maximum growth loss during these periods also coincide:

- late 1750's to late 1770's - in GAR and OSH.

- 1790's to 1810's or 1820's - all four study areas, and 1806 is the maximum growth loss year in GAR, OSH and BRN.

- mid 1820's to late 1830's - in CPN, GAR, and BRN, and 1829 is the year of maximum growth loss in CPN and GAR.

- late 1850's to late 1870's - all four study areas with wide variation in beginning and ending dates. 1872 is the year of maximum growth loss in OSH and BRN while it is 1875 in GAR.

- late 1880's to 1900 - all four study areas. Growth loss ends before 1900 in CPN, GAR and BRN but continues at OSH until 1910. Years of maximum growth loss were 1894, 1895, 1892 and 1902 respectively for the above areas.

Table 4. Approximate dates and intervals between inferred and known budworm outbreaks. Known outbreaks are indicated with an asterisk. Column A under Interval Between Periods is the number of years from the last year of the previous period to the first year of the next period; while column B is the number of years between the fist years of identified outbreaks.

Study Area and Outbreak Period	Year of Max. Growth Loss	No. of Years In Period	Interval Between Periods A	Interval Between Periods B	% Max. 1 Year Growth Loss	% Periodic Growth Loss
Capulin Canyon						
1793-1799	1794	7	-	-	43.2	15.8
1826-1831	1829	6	27	33	27.9	14.3
1845-1866	1860	22	14	19	35.6	13.5
1889-1899	1894	11	23	44	26.9	11.9
*1938-1950	1944	13	39	49	59.7	24.0
*1959-1966	1961	8	9	21	37.7	23.5
*1977-1981	1981	5	11	18	52.4	8.5
Garcia Park						
1756-1776	1763	21	-	-	50.7	18.7
1794-1814	1806	21	18	38	36.6	19.0
1824-1837	1829	14	10	30	38.9	11.3
1866-1879	1875	14	29	42	39.8	13.7
1885-1899	1895	15	6	19	59.4	26.6
*1937-1951	1945	15	38	52	47.5	21.1
*1960-1966	1964	7	9	23	47.0	24.1
*1976-1981	1981	6	10	16	79.8	25.7

Table 4. Continued.

Study Area and Outbreak Period	Year of Max. Growth Loss	No. of Years In Period	Interval Between Periods A	Interval Between Periods B	% Max. 1 Year Growth Loss	% Periodic Growth Loss
Osha Mountain						
1714-1728	1718	15	-	-	61.8	17.9
1759-1779	1761	21	31	45	38.6	12.5
1805-1826	1806	22	26	46	55.7	20.1
1854-1879	1872	26	28	49	32.6	12.3
1889-1910	1902	22	10	35	33.5	16.4
*1939-1946	1943	8	29	50	48.6	25.1
*1959-1969	1967	11	13	20	33.8	19.7
Burned Mountain						
1805-1816	1806	12	-	-	60.7	28.8
1832-1837	1834	6	16	27	32.4	18.8
1869-1876	1872	8	32	37	31.4	23.8
1885-1895	1892	11	9	16	40.2	15.9
1913-1921	1916	9	18	28	47.7	19.7
*1927-1944	1935	18	6	14	39.6	24.3
*1975-1983	1976	9	31	48	57.0	10.1
Mean[1]		14.0	19.7	32.8	42.5	19.0
S. Dev.		6.0	10.5	12.9	10.5	5.0

[1] Statistics for the intervals between periods includes the 1970's periods, while all other computations exclude this period. See text for explanation.

Although the simultaneity of budworm outbreaks between study areas is not perfectly consistent, the correspondence does appear to indicate that budworm outbreaks were an area-wide phenomenon. The lack of a very close agreement of periods might also be expected because budworm outbreaks are rather patchy and the timing of occurrence and population declines are known to vary widely within relatively small geographic areas (Johnson and Denton 1975, Kemp et al. 1985). The consistent overlap of inferred outbreaks, and especially the matching of maximum years of growth loss for some periods and study areas, is viewed as supportive evidence of the hypothesis that these periods were caused by budworm defoliation.

There are, of course, other possible explanations for these low growth periods. Blais (1962, 1965, 1983) utilized host/non-host tree-ring comparisons to reconstruct past outbreaks of spruce budworm (C. fumiferana Clemens) in eastern Canada, but he ruled out other environmental factors as causes of observed growth declines in host trees. Insects or other forest diseases might have caused the observed low growth periods; however, there are no known pests that have occurred in northern New Mexico that are specific to both Douglas-fir and white fir that would cause the observed long-lasting growth declines over such dispersed areas.

Another possibility is that there is a systematic differential response of the host and non-host species to climatic variations. However, in order for this sort of phenomenon to be reflected only during certain periods in the corrected indices would require that the regional climatic conditions fluctuate in a cyclic manner, with the growth response of the host and non-host species being similar during one phase and then different during the opposite phase. This type of differential response of tree species to climate has not been observed, and it is an unlikely explaination of the observations.

Considering that (1) damage by other pests or diseases does not seem likely, (2) both Douglas-fir and white fir tree-ring series show growth decline during the same or similar periods in widely separated sites and (3) the twentieth century periods verify well with records of budworm outbreaks, the most reasonable conclusion is that the observed extended periods of low corrected indices represent the effects of western spruce budworm defoliation.

Duration, Intervals, and Severity of Outbreaks. Computations of the duration, intervals between outbreaks, and growth losses during individual outbreaks are included in Table 4. The mean values for these estimates are given at the bottom of Table 4. With the exception of the interval between outbreaks, the current outbreak was excluded from these computations because this is an ongoing infestation and so the duration and growth loss values for this period would introduce some bias.

The average number of years (rounded) in duration, interval between outbreaks, and interval between the first years of outbreaks are 14, 20 and 33 years respectively. There was considerable variation in the duration of individual periods and intervals, however, with coefficients of variation of 43%, 53%, and 39% respectively. The measures of growth loss were less variable, with the average maximum one year growth loss equal to 42.5% and a coefficient of variation of 25%; average periodic growth loss was 19% with a coefficient of variation of 26%.

Inspection of the data on inferred outbreaks through the current outbreak (Table 4) does not reveal any definite trend toward increasing or decreasing intervals between outbreaks, intervals between maximum growth loss years or toward increasing or decreasing growth losses. Duration of outbreaks appears to be somewhat shorter, however, during the twentieth century than for earlier periods. The mean duration of twentieth century outbreaks, excluding the current outbreak, is 11.1 years, while the mean duration for earlier outbreaks was 15.2 years. These mean values are significantly different ($p < .027$, $t = -2.01$). However, only 2 outbreak periods are included in the twentieth century mean, so it may be too early to determine if this is a genuine trend.

Consideration should also be given to the fact that the estimates of duration probably include one or several years of recovery, when defoliation may have ended but tree growth remained below the expected value. It is also possible that there was a one or two year lag between the first year of defoliation and radial growth loss in lower stem (Duff and Nolan 1953, Mott et al. 1957, Alfaro et al. 1982). If this occurred, then it may have offset the additional years in the period due to recovery. In any case, the duration computed here must be considered an estimate of the number of years of reduced growth caused by budworms, and not necessarily the years of defoliation.

These estimates of duration are somewhat longer than the estimates reported by Johnson and Denton (1975) for the northern Rocky Mountain area. They conducted a very extensive review of historical records and found that outbreaks usually lasted from 1 to 5 years but occaisionally persisted for 10 or more years. The outbreaks tended to persist longer in the more humid grand fir (Abies grandis) and Douglas-fir stands of northern Idaho and Montana and in the drier forests east of the continental divide in Montana. The longest outbreak period of 18 years was recorded in the latter zone.

A direct comparison of Johnson and Denton (1975) duration estimates and the New Mexico estimates may not be completely valid because the former was generally based on records of visual defoliation. However, even when the average duration is reduced by half (to 7 years) to adjust for possible years of recovery, the New Mexico estimates still appear to be longer than those for the more mesic sites in the northern Rockies.

The New Mexico sites can be considered to be relatively dry Douglas-fir stands, partly because the sampling scheme was intended to select for these types of sites. However, it is believed that these drier sites are probably fairly typical of the Douglas-fir and mixed conifer stands in the Southern Rockies that are currently infested by budworms.

Evidence of Stand Mortality. During the process of standardizing the ring-width series from Osha Mountain and Garcia Park an interesting feature was observed in many of the oldest trees. Figure 5 shows a set of ring-width series of individual cores from the six oldest Douglas-fir trees that were sampled in 1982 at Osha Mountain, block 16. The series show the typical age-related growth trend from the pith area to about 1900, then a sudden increase in growth takes place. Four additional older trees were sampled near block 16 in 1985 and the same type of growth release after 1900 was noted in the ring-width series.

All of the other trees sampled in this block in 1982 and 1984 were much younger and most appeared to have germinated between 1900 and 1920. This stand recognizably has two well defined age classes composed of a few large trees exceeding 200 years and a much greater number of smaller young trees approximately 70 years in age (see Table 1 for species and size class distribution of block 16, and Appendix A for sample depth of the Douglas-fir series at Osha Mountain). This distribution is also visible at the site with the few large older trees towering above the the younger age class (Figure 6).

At the bottom of Figure 5 is the average index series of the six trees shown above, plus six other trees sampled in 1982 at block 16. Several of the inferred budworm outbreaks that were identified from the average corrected series of all Osha Mountain host trees (Figure 4, bottom plot) are also visible on this plot. For example, periods of low growth are visible during the 1820's and 1870's and again in the late 1890's. The three trees shown at the top of Figure 5 sustained growth loss into the 1910's and do not release until late in this decade. The three trees at the bottom of Figure 5 begin to release at about 1900.

The above observations clearly suggest that a major disturbance took place at block 16 around the turn of the century, and that the older trees that remain are the remnants of that stand. It is believed that this disturbance was a severe budworm outbreak from about 1889 to 1910, and this outbreak closely followed a previous outbreak in the 1870's (see Figure 4). The growth release of the older remnant trees suggest that there was considerable mortality of competing trees. Many trees that may have died during this period were observed in various stages of decay on the forest floor, and a few snags that may have been of the older age class were also observed at the site.

Figure 5. Ring-width series from six of the oldest Douglas-firs sampled at Osha Mountain, block 16. Smooth curves overlaying the ring-width series are cubic splines used to remove the long term trend in the series (standardization) that is due primarily to age effects and bole geometry (Cook and Peters 1981). The effects of inferred budworm outbreaks are visible during the nineteenth century in the average index plot shown at the bottom. A non-synchronous growth release is observed after 1900.

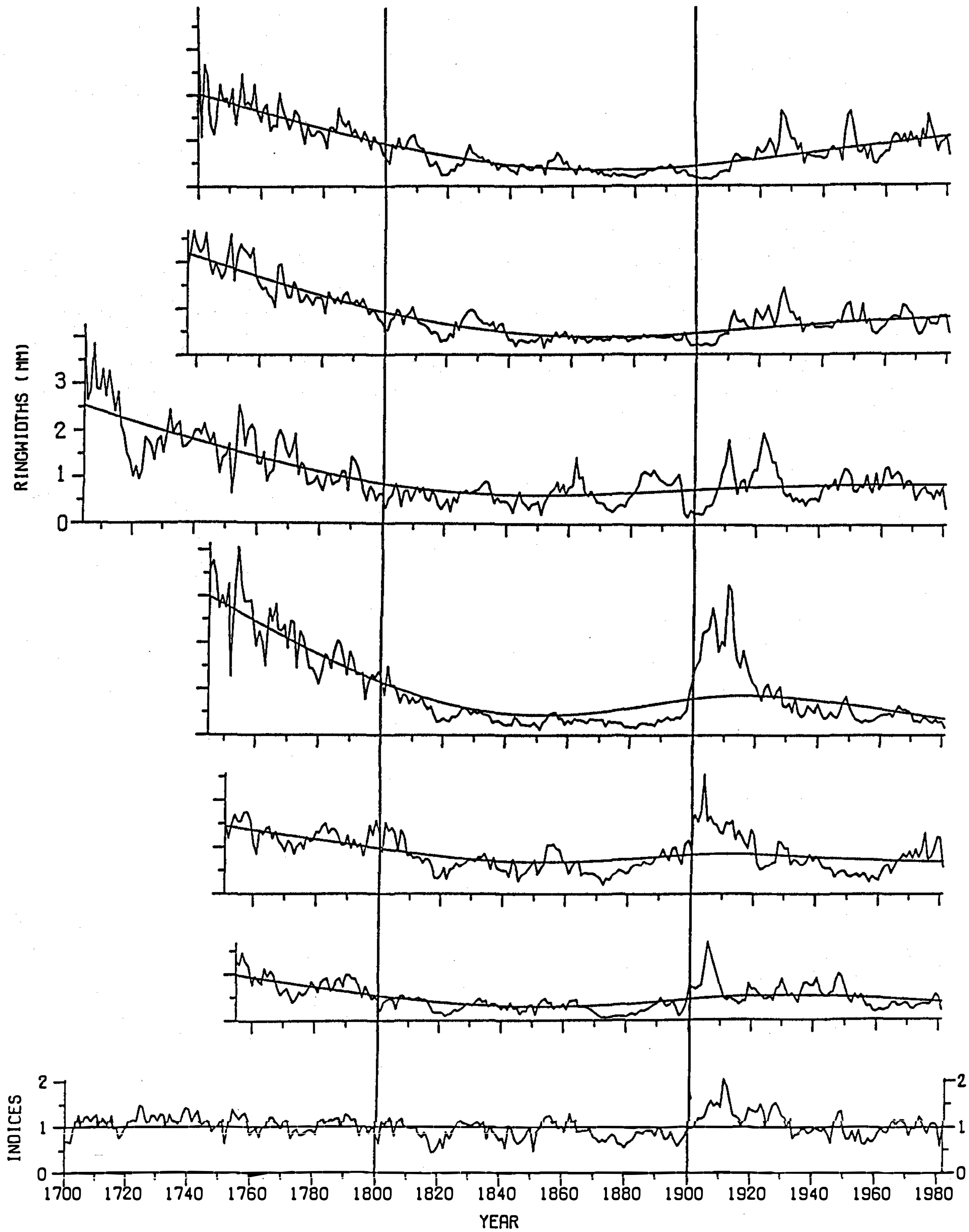


Figure 6. The large Douglas-fir in the center of this photograph is more than 250 years old, while the majority of trees at this site (Osha Mountain, block 16) are of the same age as the smaller trees in the right foreground. The smaller trees are approximately 70 years old.

Establishment of the younger age class of trees (primarily Engelmann spruce [Picea engelmannii] and subalpine firs [Abies lasciocarpa]), following the disturbance suggests an opening of the canopy. Both of these species are relatively shade tolerant and can establish under a canopy of older trees, but widespread establishment of these species will often follow a disturbance (Fowells 1965). The presence of a smaller component of moderately shade intolerant Douglas-fir trees of the same age class also indicates an opening of the stand.

It should be noted that the first two decades of the twentieth century were generally wetter than average in the northern Rio Grande area (Schulman 1956) and this may have favored tree recruitment and growth. The ponderosa pine growth indices (Appendix A) were also greater than expected during this period. Therefore, the average corrected series from Osha Mountain (bottom plot, Figure 4) does not show the post-1900 growth release because of a combination of the "correcting effect" of the ponderosa pine growth indices, and the fact that more than 50 younger trees that do not show the growth release are averaged into the series between 1900 and 1929.

Growth release from reduced competition can be due to many different types of disturbances, such as fires, blowdown, logging and insects (Lorimer 1985). However, several lines of evidence indicate that these other possible causes can be discounted: (1) No fires scars were found on trees within or near block 16, and no charring of bark on living trees or of the downed logs or snags was noted. (2) No cut stumps were seen in the area that might indicate a timber harvest. (3) The growth release observed in the ring-width series begins at different times in different trees. This would be more like the pattern expected from insect caused mortality, where trees tend to die at different times in the stand. In contrast, mortality caused by fire, blowdown, logging or some other sudden event might be expected to result in a more synchronous growth release of surviving trees. (4) Similar budworm outbreaks were inferred during approximately the same period in all of the other study areas (see Figure 4), and a few of the oldest trees at Garcia Park exhibited a very similar growth release after 1908.

The effects of growth release at Garcia Park are observable in the average corrected series (Figure 4). In this case, most of the trees included in the collection were established before 1900 and so the growth release is preserved in the series and not averaged downward by the inclusion of younger trees as was the case in the Osha Mountain series. Also notice that the apparent severity of the 1890's growth decline at Garcia Park is the highest of all periods, except the maximum year of growth loss for the current outbreak (Figure 4, Table 4).

Individual Tree Growth Loss Estimates

Chronologies for individual host trees were produced by averaging the two increment core samples from each tree, then these tree chronologies were processed through the correction procedure. The result of this process were corrected tree index series that were used to determine growth losses in the individual host trees from each study area. Figures 7 and 8 show histograms of the distributions of individual tree radial growth losses in the study areas by species and outbreak period.

The histograms show that most of the periods have normal or near-normal growth loss distributions. The current outbreak period (1975-1981) shows more skewed growth loss distributions, probably because this outbreak is ongoing and therefore the estimates from these periods do not include the full range of values that result from a complete outbreak period.

Tables 5 and 6 list the means, medians and standard deviations for these growth loss estimates. The median values of maximum one year growth losses range from 15.0% to 71.5%, while the average of all the values shown in Figure 7 is 57.1%. Notice that during most periods at least a few trees sustain a maximum one year growth loss of 100%. The median values of the periodic growth losses (Figure 8) range from -9.0% to 36.9%. The average of all values shown in Figure 8 is 22.8%.

The -9.0% value for the white fir at Capulin Canyon during the 1975-1981 period indicates that when all years in all trees are considered the growth is actually 9.0% greater than expected. The lowest median maximum one year growth loss of 20.0% was also recorded for this species and site. Therefore, the white fir trees have sustained growth losses during single years at this site during the current outbreak, but when the entire period is considered no growth loss is measured. The Douglas-fir at Capulin Canyon also sustained a median periodic growth loss of only 2.2% for this period but a median maximum one year growth loss of 49.0%. This indicates that effects of defoliation, which began about 1978, were negligible for the whole period, but measurably high during individual years.

The other distributions of periodic growth loss show that only a few trees sustained no growth loss during the outbreak periods (bars to the left of 0 in Figure 8). Most of the periodic growth loss estimates are greater than 25%. The indicated periods at the top of Figures 7 and 8 are inclusive years and the actual computed periods vary by plus or minus one or two years in either direction, depending on the observed periods of growth loss among the majority of trees sampled from each block.

Figure 7. Histograms showing distributions of maximum one year radial growth loss in Douglas-fir and white fir trees from four study areas. Vertical lines with numbers are median values.

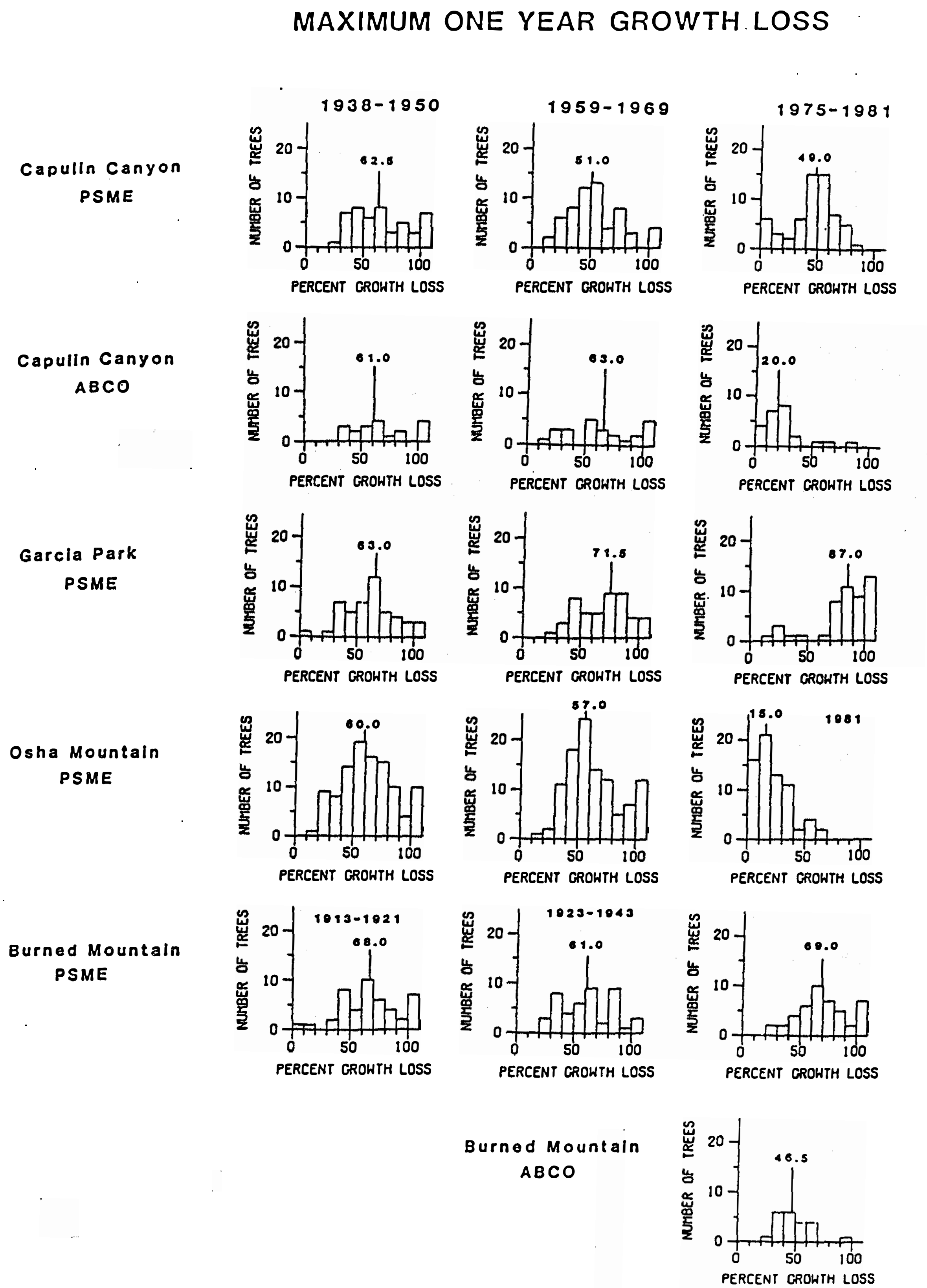


Figure 8. Histograms showing distributions of periodic radial growth loss in Douglas-fir and white fir from four study areas. Vertical lines with numbers are median values.

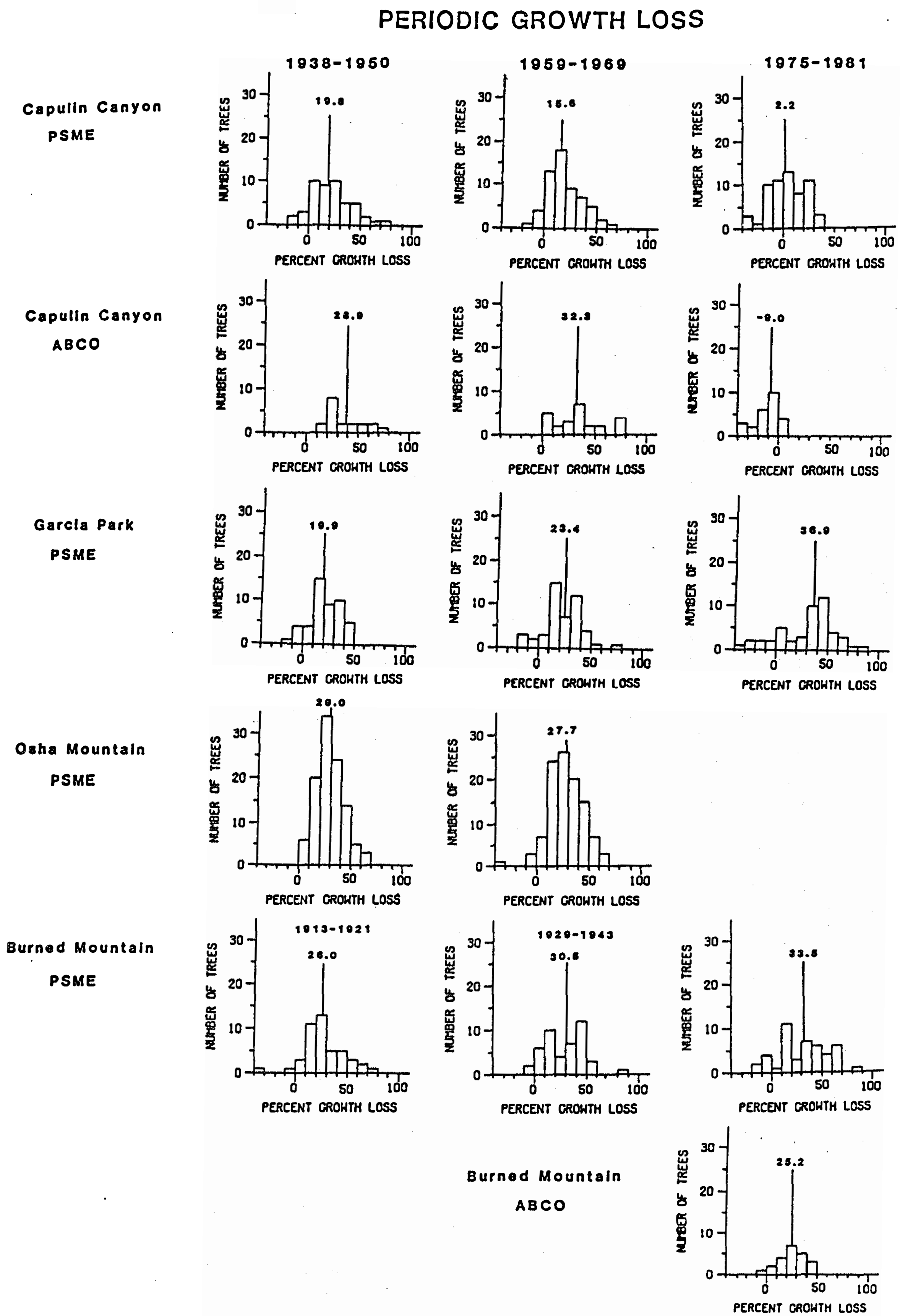


Table 5. Maximum one year radial growth loss (%) by study area and species. PSME = *Pseudotsuga menziesii*, ABCO = *Abies concolor*.

Study Area Species	n[1]	Mean	Median	SDev.	n[1]	Mean	Median	SDev.	n[1]	Mean	Median	SDev.
Capulin Canyon		(1938-1950)				(1960-1969)				(1978-1981)		
PSME	48	64.8	62.5	22.9	60	53.7	51.0	21.3	60	45.6*	49.0	19.3
ABCO	19	67.1	61.0	22.8	25	62.9	63.0	28.9	25	23.0*	20.0	22.3
Garcia Park		(1938-1950)				(1960-1969)				(1975-1981)		
PSME	48	62.2	63.0	21.4	48	69.3	71.5	20.6	48	81.6	87.0	22.9
Osha Mountain		(1939-1946)				(1959-1969)				(1981)		
PSME	106	61.7	60.0	22.6	106	62.7	57.0	21.7	80	16.7	15.0	19.2
Burned Mountain		(1913-1921)				(1929-1943)				(1975-1978)		
PSME	45	66.6	68.0	23.3	45	61.0	61.0	22.7	45	69.3*	69.0	21.7
ABCO									22	44.9*	46.5	14.2

[1] Number of trees included in each period.

* Means of PSME and ABCO are significantly different at $p < 0.05$.

Table 6. Periodic Radial Growth Loss (%) by Study Area and Species. PSME = *Pseudotsuga menziesii*, ABCO = *Abies concolor*.

Study Area Species	n[1]	Mean	Median	SDev.	n[1]	Mean	Median	SDev.	n[1]	Mean	Median	SDev.
Capulin Canyon		(1938-1950)				(1960-1969)				(1978-1981)		
PSME	48	21.6*	19.8	19.3	60	19.6*	15.6	16.5	60	3.1*	2.2	18.0
ABCO	19	35.8*	28.9	18.7	25	34.3*	32.3	23.4	25	-15.5*	-9.0	22.6
Garcia Park		(1938-1950)				(1960-1969)				(1975-1981)		
PSME	48	21.1	19.9	14.4	48	22.7	23.4	17.7	48	30.1	36.9	27.0
Osha Mountain		(1939-1946)				(1959-1969)						
PSME	106	29.7	29.0	13.8	106	27.8	27.7	17.0				
Burned Mountain		(1913-1921)				(1929-1943)				(1975-1978)		
PSME	45	28.0	26.0	18.7	45	29.1	30.5	18.7	45	31.3	33.5	25.4
ABCO									22	24.6	25.2	13.6

[1] Number of trees included in each period.

* Means of PSME and ABCO are significantly different at $p < 0.05$.

The earlier report on this study (Swetnam 1984) computed the five-year growth loss estimate. In this case, the maximum year of growth loss was used as the central value and the two years on either side were included in the computation of growth loss. The average five-year growth loss for the three outbreaks estimated from 44 host trees was approximately 35%. The lower average periodic growth loss of 20.8% includes periods between 7 and 13 years and data from 306 host trees.

The mean values of growth losses by study area computed from the individual trees differ somewhat from the mean values computed from the corrected average site chronologies shown in Table 4. This occurs because in the correction process the non-host series is rescaled to the approximate variance of the series that is to be corrected, then the residual of the non-host series (1.00 minus each value in the non-host series) is subtracted from the host series. Thus, for each host tree that was corrected the non-host series was rescaled. This results in a more individualized estimate of growth losses that is based on each tree and allows for observation of the distribution of growth losses among trees for each study area (Figures 7 and 8).

<u>Comparison of Radial Growth Losses in Douglas-fir and White Fir.</u> Figure 9 shows the corrected index plots of white fir and Douglas-fir from Capulin Canyon and Burned Mountain. The white fir indices from Capulin Canyon appear to exhibit low values for longer periods than the Douglas-fir indices during the 1940's and 1960's. The Douglas-fir series has a lower index value for 1981 than the white fir series. The timing of earlier inferred outbreak periods also seems to correspond well but differences do not appear to be as obvious as for the twentieth century outbreaks.

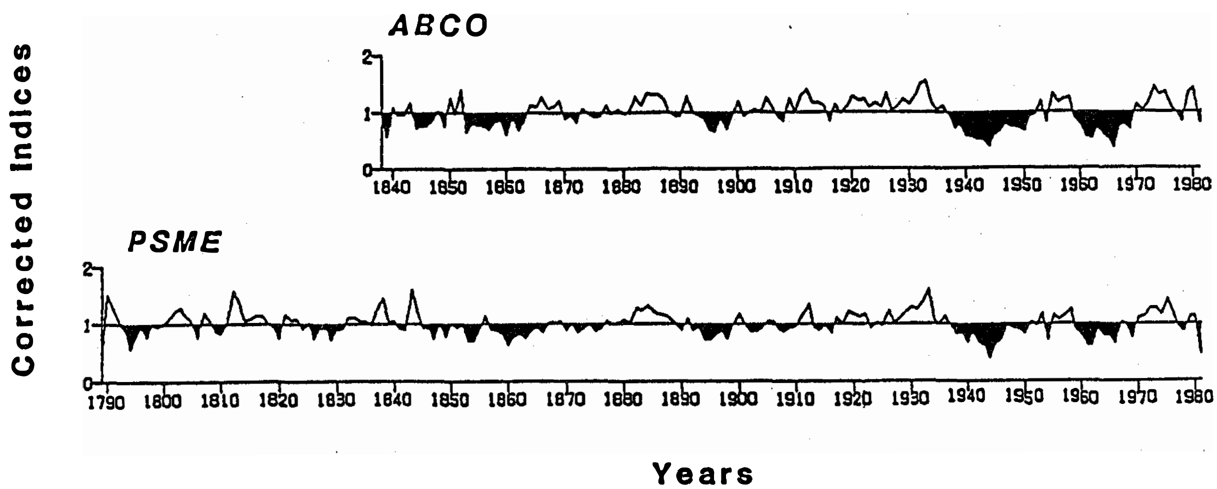
The Burned Mountain white fir and Douglas-fir series show differences in timing and duration of outbreaks. The Douglas-fir series shows very low indices during the mid 1970's, with a period of three years of approximately normal growth before declining again in 1982. The white fir series shows low indices throughout the late 1970's with approximately normal growth in 1983. Earlier periods of possible outbreak seem to overlap between the species, but severity and duration are different.

Means were tested to determine if any differences could be detected between the growth loss estimates derived from the two species for the twentieth century outbreaks. The null hypothesis was that there was no difference in mean growth loss estimates of white fir and Douglas-fir. The 1940's, 1960's and current outbreaks were tested for Capulin Canyon, while only the current outbreak period was tested for Burned Mountain.

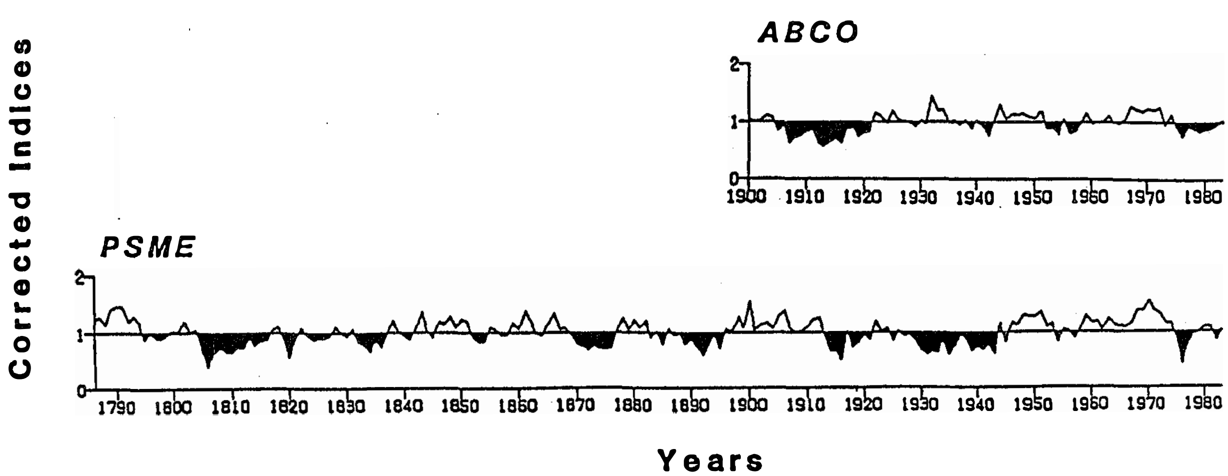
Tables 5 and 6 list the growth estimates by species and periods, and significant differences determined by a two-sample t-test are indicated with an asterisk. The results indicate that the mean maximum one year growth loss estimates are significantly

Figure 9. Comparison of average Douglas-fir (PSME) and white fir (ABCO) corrected index series.

Capulin Canyon



Burned Mountain



different only for the current outbreak at Capulin Canyon and Burned Mountain. In both cases the growth losses are greater in the Douglas-fir. However, all of the periodic growth loss estimates are significantly different between the two species at Capulin Canyon, while they are not significantly different at Burned Mountain. The periodic growth loss estimates are at least 14% greater in the white fir during the 1940's and 1960's outbreaks, but during the current outbreak growth was greater than expected in the white fir and only a slight growth loss was measured in the Douglas-fir.

Although these results appear somewhat conflicting, some general observations can be drawn from them. The periodic growth losses in white fir were greater than in Douglas-fir when the entire outbreak period was included in the estimates, but when only part of the outbreak period is tested, such as for the current outbreak, the differences are not significant or Douglas-fir growth losses are slightly greater. This may be an indication that Douglas-fir sustains growth loss sooner than the white fir in an outbreak, but for a complete outbreak cycle white fir sustains greater cumulative growth loss.

Unfortunately the number of species combinations and periods tested here is too small to provide a thorough test of species differences. Nevertheless, if the results from the current outbreak comparisons are disregarded because these periods do not include the complete outbreak cycle, the remaining comparisons of the 1940's and 1960's outbreaks at Capulin Canyon seem to confirm other findings that true firs (*Abies spp*), or more shade tolerant species in mixed stands, sustain greater growth losses from budworm defoliation than Douglas-fir (Brubaker and Greene 1979, Carlson *et al*. 1983, Johnson and Denton 1975, Williams 1967).

Comparison of Radial Growth Losses in Old and Young Age Classes. The stratification of all Douglas-fir trees into "old" and "young" age classes was relatively easy because the distribution of the earliest dated rings in trees tended to cluster in two or three groups. This indicates that the age structure of the Douglas-fir trees in these stands can be characterized as composed of relatively even aged groups.

The years used to divide the groups in each study area were 1850 for Burned Mountain and Garcia Park, 1900 for Capulin Canyon and 1910 for Osha Mountain. For example, all Garcia Park and Burned Mountain trees with earliest dated rings before and up to 1850 were included in the old age group, while all trees with earliest dated rings of 1851 and later years were included in the young age group. This division was not as artificial as it might sound, because as previously mentioned, the age classes tended to cluster in groups and nearly all trees had earliest dates greater than 10 years to either side of these dividing years. The old and young age classes, respectively, were also observed to generally fall into the sawtimber and pole size classes (defined

in Table 1), and therefore the age class statistical comparisons can be considered tests of size class differences as well.

The white fir series were not stratified by age class because the number of samples from each study area was considered to be too small for an adequate comparison, and nearly all trees at the two study areas were of the same age class.

Tables 7 and 8 list the results of computations of the means, medians and standard deviations of the different age classes by study area and outbreak period. The number of samples included in each group and the average age of each group is also listed. Means were tested to determine if differences were significant.

In general, the old age classes of trees appear to sustain greater growth losses than the younger age classes. The average maximum growth loss for all periods in the old group was 64.2% while it was 57.3% in the young group ($p = 0.16$, $t = -1.02$). The average periodic growth loss for all periods was 26.8% in the old group while it was 22.7% in the young group ($p = 0.16$, $t = -1.00$). Eight of the twelve comparisons in Table 7 show greater mean maximum growth losses in the old trees than in the young trees, while seven of the eleven comparisons in Table 8 show greater periodic growth losses in the old age classes than in the younger age classes. However, only 5 of these comparisons show significant differences ($p < 0.05$) between age classes, and 1 of these comparisons shows a greater growth loss in the younger age group.

Carlson et al. (1981) stated that published research on age of trees in relation to susceptibility and vulnerability to damage by budworms was lacking in the west, but they found that the eastern literature supports the contention that older trees and stands are more susceptible and vulnerable than younger trees. Redak and Cates (1984) found that younger Douglas-fir trees in northern New Mexico were apparently more resistant to budworms than older trees. The results reported here support the observation that younger trees within mixed age class stands sustain lower growth losses than older trees.

Table 7. Maximum one year radial growth loss (%) of Douglas-fir trees by study area and age class.

Study Area Age Class[1]	n[2]	Mean	Median	SDev.	n[2]	Mean	Median	SDev.	n[2]	Mean	Median	SDev.
Capulin Canyon		(1938-1950)				(1960-1969)				(1978-1981)		
Young (61)	32	58.9*	54.5	21.1	44	46.6*	44.5	18.2	44	44.6	46.5	18.1
Old (125)	16	76.7*	80.0	22.3	16	73.2*	69.5	16.9	16	48.2	49.5	22.8
Garcia Park		(1938-1950)				(1960-1969)				(1975-1981)		
Young (107)	19	58.2	59.0	19.0	19	70.4	76.0	21.1	19	82.2	87.0	21.1
Old (220)	29	64.8	65.0	22.8	29	68.5	72.0	20.7	29	81.2	89.0	24.3
Osha Mountain		(1939-1946)				(1959-1969)				(1981)		
Young (71)	55	63.1	59.0	20.7	55	59.0	55.0	19.5	51	13.8	15.0	15.5
Old (134)	51	60.3	61.0	24.5	51	66.6	61.0	23.3	29	21.8	17.0	23.8
Burned Mountain		(1913-1921)				(1929-1943)				(1975-1978)		
Young (107)	29	63.1	64.0	22.1	29	61.8	64.0	23.7	29	65.4	66.0	16.7
Old (237)	16	72.9	69.0	24.7	16	59.4	58.0	21.3	16	76.3	86.0	27.8

[1] Approximate average age in parenthesis. See text for explanation.

[2] Number of trees included in each period.

* Means of Young and Old age classes are significantly different at $p < 0.05$.

Table 8. Periodic radial growth loss (%) of Douglas-fir trees by study area and age class.

Study Area Age Class[1]	n[2]	Mean	Median	SDev.	n[2]	Mean	Median	SDev.	n[2]	Mean	Median	SDev.
Capulin Canyon		(1938-1950)				(1960-1969)				(1978-1981)		
Young (61)	32	18.9	16.0	14.5	44	14.0*	11.8	12.7	44	2.9	1.6	14.4
Old (125)	16	27.0	22.5	26.2	16	35.2*	36.6	15.9	16	3.7	13.1	26.2
Garcia Park		(1938-1950)				(1960-1969)				(1975-1981)		
Young (107)	19	20.1	17.5	12.7	19	19.6	22.6	18.5	19	31.8	39.1	23.6
Old (220)	29	21.7	24.8	15.6	29	24.8	24.1	17.2	29	29.0	36.1	29.3
Osha Mountain		(1939-1946)				(1959-1969)						
Young (71)	55	30.6	29.0	13.2	55	28.4	28.8	15.7				
Old (134)	51	28.8	29.0	14.5	51	27.3	25.3	18.4				
Burned Mountain		(1913-1921)				(1929-1943)				(1975-1978)		
Young (107)	29	25.0	25.5	13.5	29	33.5*	34.1	18.7	29	25.4*	27.5	20.2
Old (237)	16	33.6	32.2	25.1	16	21.2*	18.2	16.3	16	42.1*	50.5	30.5

1 Approximate average age in parenthesis. See text for explanation.

2 Number of trees included in each period.

* Means of Young and Old age classes are significantly different at $p < 0.05$.

Correlation of Defoliation, Insect Populations, and Radial Growth

The annual defoliation and insect population parameters were measured by the Forest Service on 20 to 25 trees in each of the study blocks from 1978 to 1983. However, these measurements were taken from only 10 trees per year within each block from 1978 to 1982, and five trees within each block in 1983. This sampling strategy was followed because the samples were obtained by cutting branches at the mid-crown level, therefore, in order to minimize impact on individual trees, different trees were usually sampled in successive years (Rogers 1984). As a consequence, the defoliation and insect population data are available for only 2 or three years for each tree, and these data are usually not for consecutive years. Thus, it was not possible to analyze the progressive effects of defoliation on tree growth on an individual tree basis.

As a starting point for the analysis, defoliation data for all sampled trees in the study blocks were grouped by years and compared with the corresponding years of indexed radial growth from the same trees. Table 9 shows the correlation coefficients for these comparisons. The blocks included in this analysis were 5 and 6 at Capulin Canyon, 2 at Garcia Park, 17 at Burned Mountain, and 13 through 16 at Osha Mountain. The total number of trees included in the analysis was 173, but the actual number of trees used in the individual year comparisons is less, because as mentioned above, only ten or five trees were sampled per year in each block.

The correlation coefficients in Table 9 generally show that there is an inverse relationship between defoliation and tree growth, and that this relationship changes through time. The strength of the defoliation/index inverse relationship increases from 1978 to 1981, but the correlation coefficient reverses sign in 1982 and then is a low negative value in 1983. The corrected index comparison shows a positive correlation in 1978 and thereafter shows a weaker negative correlation than the index comparison. The corrected index comparison ends in 1981 because this was the last year that the non-host trees were sampled, so corrected indices could only be computed up to this year.

The year-to-year changes in correlation shown in Table 9 are probably due to interactions of several factors. These include a possible lag of one or two years between defoliation and growth reduction in the lower stem, especially during the first few years of an outbreak (Alfaro *et al*. 1982). Interactions of climate, insect populations and tree growth may also account for some of the observed differences in correlations shown in Table 9.

Table 9. Correlation coefficents (r) of percent annual defoliation and radial growth of individual trees grouped by year.

Year(s)	Corrected Indices		Indices	
	n [1]	r	n [1]	r
1978	19	.487*	19	-.268
1979	68	-.285*	68	-.310*
1980	75	-.226*	75	-.567**
1981	75	-.324*	75	-.603**
1982	-	-	75	.439**
1983	-	-	37	-.102
1978-1981	237	-.387**	237	-.581**
1978-1983	-	-	349	-.233**

[1] n is the number of data pairs and is equivalent to number of trees for the single year correlations.

* $p < 0.05$.
** $p < 0.001$.

Correlations are generally higher in the defoliation/index comparisons than in the defoliation/corrected index comparisons. It was originally thought that the corrected indices would contain a stronger defoliation signal because the confounding effects of climate have been removed (or at least mitigated). However, the higher correlations in the index comparisons suggests that the correction procedure somehow removes a portion of the variability in the tree growth that is explained by the defoliation record, or perhaps some other noise component is introduced by the procedure. It may be that the climate component explains some of the variability in defoliation through effects on the insect population.

(Although the indices apparently include a stronger defoliation signal, the corrected indices are still considered a better estimate of tree growth losses because the bias introduced by climatic effects on tree growth is at least partially accounted for. Thus, when corrected indices are used in growth loss estimation, low precipitation or other unfavorable climate conditions occuring during an outbreak that would naturally lead to reduced growth in host and non-host trees should not result in an overestimate of growth losses due to budworms. Conversely, favorable climate conditions that lead to greater than expected growth during an outbreak, despite the effects of budworm defoliation, should not result in an underestimate of growth losses.)

The reversal in sign of the correlation coefficient from 1981 to 1982 in the defoliation/index comparison is difficult to explain. It was noted, however, that defoliation levels increased fairly steadily from 1978 to 1981, then in 1982 defoliation levels decreased by 30% or more in most of the blocks. Thus, the effects of peak defoliation in 1981 may have been partially reflected in lower tree growth in 1982 at the same time that defoliation levels were declining. This sort of lag effect could result in positive correlations. On the other hand it must be remembered that the correlations shown in Table 9 are for indiviidual tree growth measurements with individual tree defoliation levels. Therefore, increased or decreased defoliation on individual trees was related to increased or decreased tree growth respectively! This does not seem reasonable, and so at this point, the observed relationship remains unexplained. However, a number of complex interactions are probably involved, including the individual tree defoliation histories, climate, lag effects, and changes in the physiological responses of trees to budworm defoliation.

In order to circumvent the problem of individual tree variablity, and the lack of continuous year-by-year defoliation records for individual trees, the average defoliation in each block by year was compared with the average tree growth for the corresponding years. This approach also allowed for comparison of previous years average block defoliation, and cumulative average block defoliation with average block tree growth. Average block measurements of the budworm populations numbers

(egg masses, and larvae) were also compared with the average block tree growth measurements.

The resulting correlation coefficients were much higher and more significant than for the individual tree comparisons (Table 10). Correlations were generally higher in index comparisons than the corrected index comparison for 1978 to 1981, but correlations were lower in the index comparisons for 1978 to 1983. Surprisingly, the previous years defoliation level (defoliation lagged one year,[Y-1]) produced a lower correlation than current years defoliation. However, cumulative defoliation, which was the current years defoliation plus all previous years defoliation, produced quite high correlations.

The average budworm population parameters, egg mass density and larval density, also produced strong correlation coefficients in some of the comparisons. The strongest correlation (-0.745) among all comparisons was for previous years egg mass density (Y-1) and 1978 to 1981 indices. Obviously the effects of the insect populations on tree growth must be considered an indirect effect through the action of defoliation. In fact, the correlation between the insect population parameters and defoliation was generally quite strong and significant. For example, the correlation between current years defoliation and current years larval density was 0.869 ($n = 20$, $p < 0.001$).

An attempt was made to construct an empirical model of tree growth by using multiple-variable regression techniques (Draper and Smith 1981). Step-wise multiple regression was used on various combinations of defoliation and budworm population parameters as independent variables and tree growth (both corrected indices and indices) as the dependent variable. However, due to reduction of data points because of the use of lagged variables, and because of the strong co-linearity of the independent variables, a satisfactory model was not developed that explained a greater proportion of the variance in tree growth than the best one independent variable regressions. Plots of the the strongest correlated variables with tree growth and their linear regression equations are shown in Figure 10.

Two exponential models produced better results than the linear models. The equations for these models are:

$$\text{Growth Index} = 1.310 * e^{(-.004 * \text{Cumulative Defoliation})}$$

$$\text{Growth Index} = 1.180 * e^{(-.014 * \text{Egg Mass Density (Y-1)})}$$

The cumulative defoliation model resulted in an R^2 of 0.584 ($n = 28$, $p < 0.01$, $F = 11.07$), and the egg mass density model resulted in an R^2 of 0.671 ($n = 21$, $p < 0.05$, $F = 5.01$). These models

Table 10. Correlation coefficients (r) of comparisons between average block growth indices, defoliation, and insect population data. % Defoliation is percentage loss of annual foliage growth, % Cum. Defoliation is percent cumulative defoliation, Egg Masses are numbers per M^2 of foliage, and Larvae are numbers per 100 live buds.

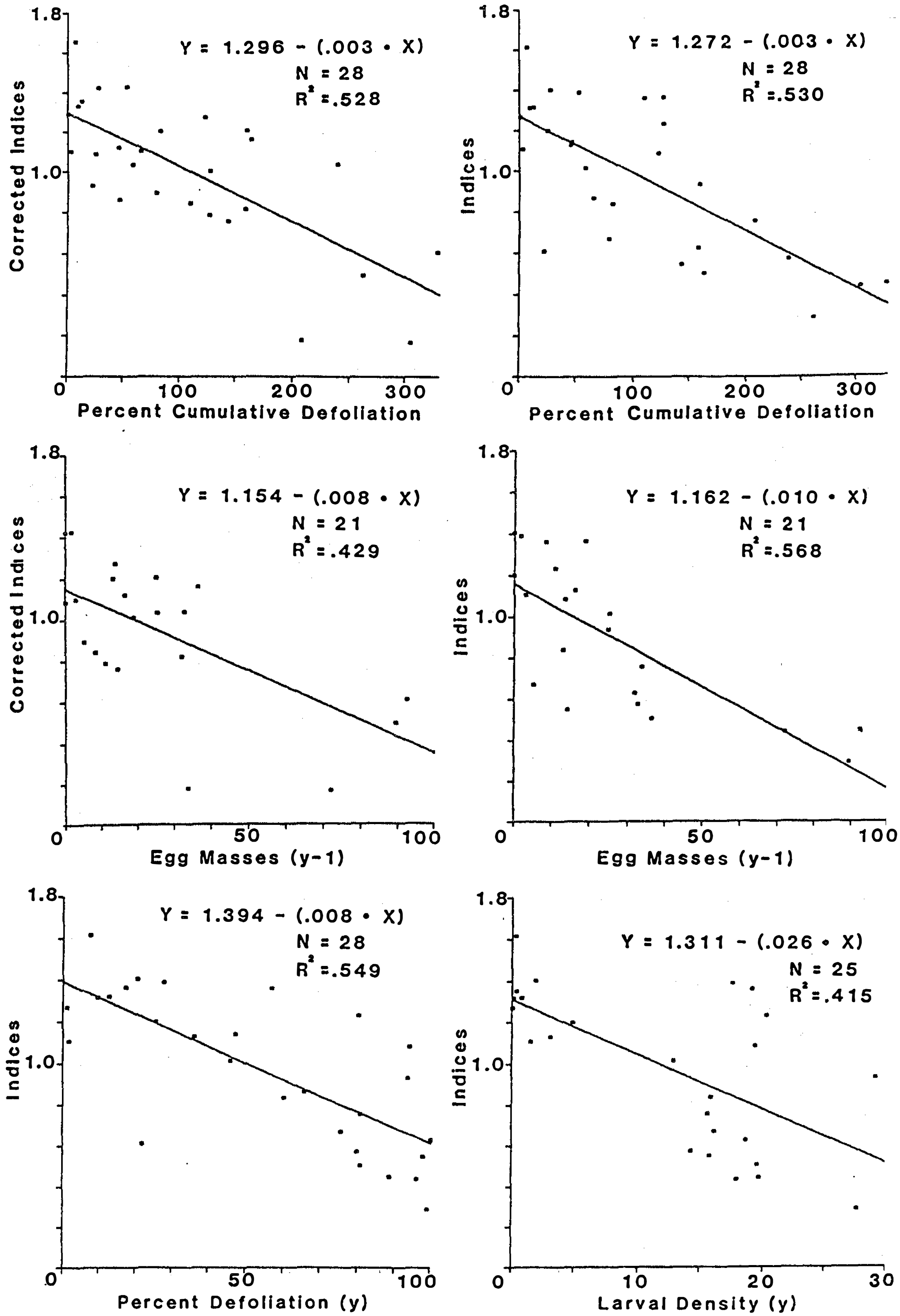
	1978-1981 Corrected Indices		1978-1981 Indices		1978-1983 Indices	
	n[2]	r	n[2]	r	n[2]	r
% Defoliation (Y[1])	28	-.616**	28	-.741**	42	-.430*
% Defoliation (Y-1)	20	-.593*	20	-.586*	33	-.185
% Cum. Defoliation	28	-.727**	28	-.728**	42	-.551**
Egg Masses (Y)	29	-.257	29	-.506*	43	-.472**
Egg Masses (Y-1)	21	-.655**	21	-.754**	35	-.562**
Larvae (Y)	25	-.506*	25	-.644**	32	-.246
Larvae (Y-1)	18	-.503*	18	-.437*	32	-.100

1 Y is current years data, Y-1 is previous years data.

2 n is number of data pairs.

* significant at $p < .05$
** significant at $p < .001$

Figure 10. Scatter plots and regression lines of defoliation, insect population data, and radial growth measurements. Regression equations, r^2 values and number of data pairs are shown with each plot.



use data from 1978 to 1981, but do not perform well with the 1982 and 1983 data, suggesting that they may be most reliable for predictive purposes during the first few years of an outbreak when the budworm populations and defoliation levels are increasing.

At this stage, the correlation and regression results reported here should be considered preliminary. Other approaches to the development of more satisfactory predictive models have yet to be investigated. One possibility is the development of a model that would use a combination of cumulative stand defoliation and individual tree defoliation to predict tree growth. Alfaro et al. (1982), describe such a model that explained 85% of the variance in individual tree growth. There is also the potential for expanding the data base by resampling the non-host trees and thereby updating the corrected index set to 1983. The author plans to pursue these and other strategies in the hope that a more effective and reliable equation can be constructed that would allow the forest manager to predict radial growth losses from defoliation and/or insect population measurements.

CONCLUSIONS

Spruce budworm outbreaks covering large areas of mixed conifer forests in northern New Mexico have occurred many times in the past and will recur in the future. The period between outbreaks, and the duration and severity of outbreaks are variable, but the estimates of these values reported here provide an indication of the range of these variabilities.

Blais (1983) summarized tree-ring studies and documented evidence of budworm outbreaks in northeastern America covering the last three centuries and concluded that frequency, severity and extent of the eastern spruce budworm outbreaks was increasing. The tree-ring data reported here do not reveal any definite increasing or decreasing trends. The scope of this study, however, has included a relatively small number of host trees and study areas that have been limited by necessary sample selection and analysis techniques. Studies involving additional areas and sample trees in the Southern Rockies, as well as compilation and analysis of historic documentation may reveal more significant trends in this region.

The estimates of radial growth loss are expressed only as a percentage of expected growth and therefore have some limitation in terms of direct application to the economic problems that forest managers must deal with. However, it is believed that, with minor modifications, the percentage radial growth loss measures could be utilized for calibration or verification of some of the components and results of growth and yield models that are currently available or are being developed. Other

possibilities include the transformation of the indexed tree-ring series back to ring widths, with or without the climate component, and then growth losses could be computed in terms of basal area increment.

There is also a need for further research and development of models that might reliably relate radial growth loss in the lower stem with growth loss at higher positions on the bole so that more accurate radial and volume loss estimates might be obtained.

Finally, the correlations between insect population numbers, defoliation, and indexed radial growth are sufficiently strong that the models described here may provide a useful approximation of radial growth losses from field observations of defoliation, and insect populations. Additional work on development and testing of better models is needed.

APPENDIX A

Tree-Ring Indices

CPL649 CAPULIN CANYON, NEW MEXICO **INDICES**
PONDEROSA PINE
LATITUDE 36 25 LONGITUDE 105 30 ELEVATION 9500 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

	TREE RING INDICES										NUMBER OF SAMPLES									
DATE	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1790	40	89	98	118	116	97	84	113	98	115	2	2	2	2	3	4	4	4	5	5
1800	135	79	71	108	107	104	110	83	103	91	7	7	7	7	7	8	8	8	8	8
1810	121	104	69	92	86	96	104	94	85	91	10	11	11	11	11	11	11	11	11	11
1820	111	87	85	86	81	101	106	122	126	115	12	12	14	14	15	15	15	15	16	16
1830	118	120	121	103	116	140	112	89	83	118	20	20	20	20	20	20	20	21	21	22
1840	125	102	80	66	97	83	62	81	67	99	23	23	23	23	23	23	24	24	24	24
1850	80	42	104	119	141	121	109	105	119	90	26	26	26	26	26	26	26	26	26	26
1860	127	117	115	108	115	81	112	99	106	121	26	26	26	26	26	26	26	26	26	26
1870	104	97	127	83	86	96	112	89	93	75	26	26	26	26	26	26	26	26	26	26
1880	56	88	97	98	105	110	98	105	106	118	26	26	26	26	26	26	26	26	26	26
1890	96	102	93	66	76	130	82	86	97	56	26	26	26	26	26	26	26	26	26	26
1900	71	76	73	108	58	63	105	142	126	104	26	26	26	26	26	26	26	26	26	26
1910	92	108	85	91	121	98	107	82	106	121	26	26	26	26	26	26	26	26	26	26
1920	95	140	52	67	63	71	93	92	78	98	26	26	26	26	26	26	26	26	26	25
1930	95	73	82	91	65	90	80	100	106	78	25	25	25	25	25	25	25	25	25	25
1940	112	128	124	130	156	121	108	117	133	155	25	25	25	25	25	25	25	25	25	25
1950	132	87	91	91	131	120	71	86	74	85	25	25	25	25	25	25	25	25	25	25
1960	117	109	122	75	98	156	171	150	133	179	25	25	25	25	25	25	25	25	25	25
1970	109	78	85	76	92	112	93	103	81	77	25	25	25	25	25	25	25	25	25	25
1980	55	89									25	25								

SERIAL CORRELATION = .392 STANDARD DEVIATION = .222 MEAN SENSITIVITY = .197 N = 194

CPNALL CAPULIN CANYON, NEW MEXICO **INDICES**

DOUGLAS-FIR
LATITUDE 36 25 LONGITUDE 105 22 ELEVATION 9500 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

	TREE RING INDICES										NUMBER OF SAMPLES									
DATE	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1790	85	116	106	109	74	75	77	91	96	111	2	2	2	2	3	3	3	3	3	3
1800	136	88	89	138	124	110	87	100	110	76	3	3	3	3	3	3	3	3	3	3
1810	106	103	124	127	90	104	119	109	86	83	4	4	4	4	4	4	4	4	4	4
1820	88	104	90	94	70	102	62	116	120	89	4	4	4	4	4	4	4	4	4	4
1830	109	114	134	114	122	150	110	117	126	125	4	4	4	4	4	4	4	6	6	6
1840	133	94	68	145	123	76	72	54	63	79	6	6	6	6	6	6	6	6	6	6
1850	78	29	103	91	115	115	122	94	110	71	6	6	6	6	6	7	7	8	8	8
1860	94	96	97	84	104	72	98	100	108	127	9	9	10	10	10	10	12	14	14	14
1870	95	98	115	73	65	63	104	93	93	76	14	14	14	14	14	14	14	14	14	14
1880	58	89	124	120	136	134	115	121	116	117	14	14	14	14	14	14	14	14	17	17
1890	65	110	82	57	47	106	61	72	71	50	17	18	18	18	20	20	20	20	20	20
1900	86	72	57	95	47	67	109	136	115	98	20	20	28	28	28	28	28	28	30	30
1910	88	124	117	65	113	96	95	92	107	145	34	34	34	36	38	38	38	39	41	43
1920	111	156	65	58	84	66	117	94	88	120	51	51	51	51	51	51	51	52	52	52
1930	124	97	119	150	68	90	91	102	89	59	56	60	61	62	64	67	68	70	70	79
1940	62	117	93	92	102	67	64	117	129	149	85	87	69	91	91	95	98	99	101	105
1950	117	88	89	108	107	137	75	100	97	74	109	109	111	111	113	113	113	113	113	113
1960	98	72	86	65	77	140	143	156	137	163	113	113	113	113	113	113	113	113	113	113
1970	122	89	111	102	110	155	112	100	66	88	113	113	113	113	113	113	113	113	113	113
1980	63	36	30	51							111	103	72	70						

SERIAL CORRELATION = .537 STANDARD DEVIATION = .253 MEAN SENSITIVITY = .242 N = 194

CPU650 CAPULIN CANYON, NEW MEXICO **INDICES**
WHITE FIR
LATITUDE 36 25 LONGITUDE 105 30 ELEVATION 9500 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

TREE RING INDICES

DATE	0	1	2	3	4	5	6	7	8	9
1840	137	100	74	103	70	57	56	65	65	77
1850	103	33	146	90	127	101	85	77	105	76
1860	94	110	88	92	131	69	141	108	119	146
1870	96	91	114	88	82	88	108	101	91	78
1880	48	88	125	111	141	145	130	130	106	114
1890	89	130	93	55	61	103	47	71	68	41
1900	87	67	70	113	53	108	115	140	115	128
1910	92	140	124	109	143	109	94	93	105	136
1920	123	168	69	72	97	76	128	94	86	121
1930	109	99	132	146	75	94	87	98	81	54
1940	72	89	79	83	103	83	77	96	111	133
1950	104	76	86	109	120	156	85	109	98	74
1960	97	68	79	43	59	116	117	133	114	160
1970	124	79	98	118	124	150	100	103	62	109
1980	91	72	70	130						

NUMBER OF SAMPLES

DATE	0	1	2	3	4	5	6	7	8	9
1840	2	2	2	2	2	2	2	2	2	2
1850	2	2	4	4	4	4	4	5	6	7
1860	8	8	6	6	8	8	8	6	6	8
1870	12	12	12	12	12	12	12	12	12	12
1880	12	12	12	12	12	12	12	12	12	12
1890	12	12	12	12	13	13	13	13	13	13
1900	13	14	14	14	14	14	14	14	14	14
1910	18	18	19	19	22	23	24	28	28	28
1920	29	29	29	30	31	31	31	32	32	32
1930	32	32	33	34	34	36	36	36	36	36
1940	36	36	37	37	37	42	43	43	43	46
1950	50	50	50	50	50	50	50	50	50	50
1960	50	50	50	50	50	50	50	50	50	50
1970	50	50	50	50	50	50	50	50	50	50
1980	49	49	49	49						

SERIAL CORRELATION = .303 STANDARD DEVIATION = .271 MEAN SENSITIVITY = .267 N = 146

GPK649 GARCIA PARK, NEW MEXICO **INDICES**
PONDEROSA PINE
LATITUDE 36 20 LONGITUDE 105 22 ELEVATION 9000 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

DATE	TREE RING INDICES 0	1	2	3	4	5	6	7	8	9	NUMBER OF SAMPLES 0	1	2	3	4	5	6	7	8	9
1621		135	95	88	80	95	106	94	72	139		1	1	1	1	1	1	1	1	1
1630	93	55	77	87	83	96	132	132	101	107	1	1	1	1	1	1	1	1	1	1
1640	151	90	127	113	112	63	59	90	69	96	2	2	2	2	2	2	2	2	2	2
1650	104	137	201	156	47	81	129	122	98	96	2	2	2	2	2	2	2	2	2	2
1660	124	187	169	150	103	161	103	113	107	139	2	2	2	2	2	2	2	2	2	2
1670	115	158	173	131	145	99	61	100	133	141	3	3	3	3	4	4	4	4	4	4
1680	166	71	63	108	59	25	69	66	146	169	4	4	4	4	4	4	4	4	4	5
1690	146	104	152	129	115	106	52	100	94	143	5	5	5	6	6	6	6	6	6	6
1700	85	149	113	129	92	101	100	53	93	85	7	7	7	7	7	8	8	8	8	8
1710	135	99	111	106	84	50	38	66	116	64	8	8	8	8	8	8	8	8	8	8
1720	160	98	91	76	112	66	144	79	45	13	8	8	8	8	8	8	8	9	9	9
1730	47	50	69	52	100	38	84	40	68	60	9	9	9	9	9	9	10	10	10	10
1740	86	67	96	127	67	110	130	127	21	98	10	10	10	10	10	10	11	11	11	11
1750	84	106	17	47	90	103	87	77	91	90	11	11	11	11	11	12	12	12	12	12
1760	111	156	155	136	169	90	102	145	160	156	12	12	12	12	12	12	12	12	12	13
1770	133	179	155	66	107	63	94	70	52	62	13	13	13	13	13	13	13	13	13	13
1780	40	49	67	92	112	96	69	144	102	91	13	13	13	13	13	14	14	14	14	14
1790	66	120	152	179	139	101	130	132	71	120	15	15	15	15	16	16	16	16	16	16
1800	132	26	90	106	121	98	73	111	64	68	16	16	16	16	16	16	16	16	16	16
1810	96	104	111	132	73	130	139	115	83	52	16	16	16	16	16	16	16	16	16	16
1820	91	123	89	97	92	136	124	146	163	139	16	16	17	17	17	17	17	17	17	17
1830	110	120	145	162	146	163	99	133	129	156	18	18	18	18	18	18	18	19	19	19
1840	151	102	35	83	94	68	38	43	39	78	20	21	21	21	21	21	21	21	21	21
1850	67	20	72	93	116	98	93	91	104	72	21	21	21	21	21	21	21	21	21	21
1860	84	32	72	67	70	73	100	121	128	133	21	21	21	21	21	21	21	21	21	21
1870	120	84	119	63	86	103	118	90	103	83	21	21	21	21	21	21	21	21	21	21
1880	32	68	114	91	125	159	157	192	161	164	21	21	21	21	21	21	21	21	21	21
1890	109	106	106	82	65	138	62	126	96	56	22	22	22	22	22	22	22	22	22	22
1900	65	67	44	104	66	103	117	151	124	114	22	22	22	22	22	22	22	22	22	22
1910	123	144	125	101	142	129	123	80	98	103	22	22	22	22	22	22	22	22	22	22
1920	108	139	57	50	77	60	66	75	84	122	22	22	22	22	22	22	22	22	22	22
1930	98	54	87	81	37	94	63	103	86	60	22	22	22	22	22	22	22	22	22	22
1940	77	128	117	103	119	135	40	97	90	111	22	22	22	22	22	22	22	22	22	22
1950	98	55	94	86	96	69	13	51	75	45	22	20	20	20	20	20	20	20	20	20
1960	106	97	111	59	118	174	156	120	120	164	20	20	20	20	20	20	20	20	20	20
1970	106	28	59	104	112	166	144	109	125	140	20	20	20	20	20	20	20	20	20	20
1980	155	129									20	20								

SERIAL CORRELATION = .486 STANDARD DEVIATION = .361 MEAN SENSITIVITY = .332 N = 361

GAR549 GARCIA PARK, NEW MEXICO **INDICES**
DOUGLAS-FIR
LATITUDE 36 20 LONGITUDE 105 23 ELEVATION 9000 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

DATE	TREE RING INDICES 0	1	2	3	4	5	6	7	8	9	NUMBER OF SAMPLES 0	1	2	3	4	5	6	7	8	9
1700	55	73	86	115	106	102	157	102	116	97	2	2	2	2	2	2	2	3	3	3
1710	167	126	142	138	104	75	78	118	154	66	5	6	6	6	6	6	6	6	6	6
1720	146	136	125	82	104	82	139	92	104	44	6	7	7	7	7	7	7	7	7	7
1730	66	110	121	77	143	78	131	65	83	89	8	8	8	8	8	8	8	8	8	8
1740	89	61	80	146	97	103	129	133	41	98	11	11	11	11	11	11	11	11	11	11
1750	75	106	33	75	89	109	73	73	78	82	13	13	13	13	13	13	13	13	13	13
1760	84	141	121	81	141	82	129	123	128	130	16	16	17	17	17	17	17	17	17	17
1770	115	164	112	63	93	74	92	79	56	67	21	21	22	25	25	25	25	25	25	25
1780	51	59	98	107	137	122	89	130	100	64	26	26	26	26	26	26	26	26	26	26
1790	118	154	148	176	122	64	113	94	58	92	28	28	29	30	30	31	31	31	31	31
1800	127	35	82	93	91	67	41	85	46	52	32	33	33	33	33	33	33	33	33	33
1810	71	84	104	117	59	134	154	124	59	57	33	33	33	33	33	33	33	33	34	34
1820	71	125	91	112	77	130	117	122	152	96	34	34	35	36	36	37	37	37	38	38
1830	118	123	133	117	132	142	79	127	145	156	41	41	42	43	43	43	43	44	44	44
1840	126	92	58	131	119	65	59	54	72	78	52	52	52	52	52	52	52	52	52	52
1850	90	30	107	96	114	123	114	102	105	84	59	59	59	59	59	59	59	59	59	59
1860	66	62	99	86	110	76	66	95	101	135	65	65	65	67	67	67	67	67	67	67
1870	79	93	116	77	64	64	106	91	89	68	71	71	71	71	71	71	71	71	71	71
1880	47	78	113	100	154	147	138	151	140	131	72	72	72	72	72	72	72	72	72	72
1890	97	130	111	58	42	74	42	66	55	37	77	77	78	78	78	78	78	78	78	78
1900	81	66	62	91	61	101	111	142	117	130	79	79	79	79	79	79	79	79	79	79
1910	127	165	165	126	154	151	109	112	117	160	87	87	87	87	87	87	87	87	87	87
1920	142	108	83	66	90	64	110	93	87	107	88	88	89	89	89	89	89	89	89	89
1930	104	78	110	146	61	106	66	99	78	55	91	91	91	91	91	91	91	91	91	91
1940	66	68	66	73	86	83	48	79	87	94	91	91	91	91	91	91	91	91	91	91
1950	85	67	75	96	106	132	75	94	125	90	91	91	91	91	91	91	91	91	91	91
1960	105	86	75	61	70	122	125	129	126	157	91	91	91	91	91	91	91	90	89	89
1970	137	68	126	137	128	134	118	96	125	144	90	90	90	90	90	90	90	89	89	87
1980	93	46									81	80								

SERIAL CORRELATION = .444 STANDARD DEVIATION = .309 MEAN SENSITIVITY = .290 N = 282

GWF659 GARCIA PARK, NEW MEXICO **INDICES**
WHITE FIR
LATITUDE 36 20 LONGITUDE 105 23 ELEVATION 9200 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

	TREE RING INDICES										NUMBER OF SAMPLES									
DATE	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1890	89	100	93	72	73	93	77	110	106	90	2	2	2	2	2	2	2	2	2	2
1900	102	104	72	106	88	87	99	91	84	90	2	2	3	3	3	5	7	7	10	11
1910	95	109	112	108	115	91	89	85	98	99	14	16	17	17	18	18	18	21	21	21
1920	94	119	98	93	105	94	106	106	96	119	29	32	36	39	39	40	40	40	40	40
1930	113	93	107	110	88	92	76	109	95	88	50	50	50	50	50	50	50	50	50	50
1940	91	99	83	111	121	123	94	95	103	104	50	50	50	50	50	50	50	50	50	50
1950	87	77	89	107	131	141	73	99	104	61	50	50	50	50	50	50	50	50	50	50
1960	100	82	81	56	69	104	118	124	123	134	50	50	50	50	50	50	50	50	50	50
1970	118	93	119	127	154	156	118	96	46	122	50	50	50	50	50	50	50	50	50	50
1980	92	60	45	60							50	48	47	47						

SERIAL CORRELATION = .457 STANDARD DEVIATION = .199 MEAN SENSITIVITY = .165 N = 94

OSM649 OSHA MOUNTAIN, NEW MEXICO **INDICES**
PONDEROSA PINE
LATITUDE 36 40 LONGITUDE 105 25 ELEVATION 9500 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

TREE RING INDICES

DATE	0	1	2	3	4	5	6	7	8	9
1581		164	152	94	87	100	102	82	89	132
1590	68	117	162	151	197	185	155	202	74	132
1600	86	99	114	125	122	107	109	134	157	129
1610	152	125	139	168	111	90	84	94	98	81
1620	72	50	35	39	27	65	51	79	55	87
1630	67	66	54	90	149	121	144	150	69	66
1640	144	138	137	101	66	21	59	49	45	74
1650	72	75	97	67	54	108	126	105	112	111
1660	150	130	126	74	75	54	44	63	68	51
1670	69	86	76	66	105	101	60	113	107	111
1680	108	46	93	118	68	72	111	118	108	127
1690	111	110	137	131	95	94	48	106	78	103
1700	72	87	95	104	92	111	134	94	114	118
1710	125	111	106	113	111	103	107	130	142	99
1720	131	110	100	105	120	111	126	85	94	58
1730	91	97	97	79	106	61	93	63	93	93
1740	98	65	110	105	94	101	116	108	63	101
1750	80	97	35	52	75	95	95	122	120	121
1760	114	129	118	110	114	107	130	123	118	104
1770	103	114	103	73	96	94	84	87	90	100
1780	76	68	102	105	113	107	109	113	118	94
1790	86	102	111	124	104	86	102	86	71	92
1800	96	33	67	79	108	118	145	145	144	117
1810	130	126	126	138	134	112	104	90	70	82
1820	100	107	96	106	94	125	120	124	127	116
1830	107	108	112	117	125	110	77	94	94	79
1840	93	89	56	77	79	62	50	54	51	57
1850	59	25	63	104	135	132	118	135	126	94
1860	112	104	119	114	109	92	102	105	100	99
1870	96	76	97	88	88	90	103	96	71	79
1880	39	53	69	73	86	99	102	113	110	110
1890	100	109	98	85	70	109	82	102	129	106
1900	124	123	121	128	102	113	120	157	132	122
1910	107	121	124	125	137	121	131	78	107	113
1920	111	125	100	119	116	79	117	105	107	114
1930	94	89	66	98	66	101	76	97	98	84
1940	96	111	118	131	119	116	66	82	96	107
1950	85	83	90	82	64	88	35	60	81	64
1960	110	101	112	91	83	127	145	151	143	164
1970	114	45	76	95	105	109	85	86	96.	99
1980	101	82								

NUMBER OF SAMPLES

0	1	2	3	4	5	6	7	8	9
	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3
3	3	4	5	5	6	7	8	9	10
11	11	12	12	15	15	15	15	15	16
18	18	16	18	18	18	19	19	19	19
21	21	23	23	23	23	23	23	23	23
24	25	25	25	25	25	25	25	25	25
25	25	25	25	25	25	25	25	25	25
26	26	26	26	26	26	26	26	26	26
26	26	26	26	27	27	27	27	28	28
28	28	28	28	28	28	28	29	29	29
29	29	29	29	29	29	29	29	29	29
29	29	29	29	29	29	29	29	29	29
30	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	31	31	31	31	31	31	31	31	31
31	30	30	30	30	30	30	30	30	30
30	30								

SERIAL CORRELATION = .615 STANDARD DEVIATION = .275 MEAN SENSITIVITY = .197 N = 401

OSHALL OSHA MOUNTAIN, NEW MEXICO **INDICES**
DOUGLAS-FIR
LATITUDE 36 40 LONGITUDE 105 25 ELEVATION 10000 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

TREE RING INDICES

DATE	0	1	2	3	4	5	6	7	8	9
1700	135	119	123	148	167	104	125	123	116	117
1710	121	114	146	121	103	99	70	94	76	70
1720	96	100	102	92	112	97	111	74	94	73
1730	81	99	104	82	112	92	95	80	104	115
1740	114	96	109	128	104	95	104	98	76	90
1750	86	101	56	86	117	112	104	118	124	111
1760	61	88	95	74	93	90	116	116	108	102
1770	90	109	100	72	87	90	82	80	84	90
1780	69	79	115	117	105	110	106	115	126	101
1790	127	120	116	119	102	83	106	99	86	105
1800	92	65	116	110	123	111	65	116	119	103
1810	110	109	111	113	98	93	102	83	53	57
1820	61	82	61	97	82	102	113	128	122	122
1830	116	112	121	121	117	121	84	105	98	93
1840	66	61	66	116	105	73	70	70	76	84
1850	94	46	97	104	125	120	119	105	111	93
1860	99	89	124	101	106	64	81	84	76	84
1870	71	71	65	73	73	65	90	84	67	73
1880	65	72	81	67	97	96	100	122	109	100
1890	77	99	96	67	73	98	71	81	96	81
1900	98	88	85	101	92	94	110	131	110	119
1910	98	136	151	122	106	100	92	90	102	126
1920	118	113	100	107	112	86	116	115	119	124
1930	122	113	114	127	75	101	92	115	103	77
1940	79	88	85	80	95	60	54	86	105	115
1950	84	71	80	108	81	119	71	78	68	71
1960	82	76	80	76	64	116	117	113	120	137
1970	121	80	108	111	122	140	114	103	123	136
1980	116	73	131	138	116					

NUMBER OF SAMPLES

0	1	2	3	4	5	6	7	8	9
1	1	1	1	2	2	2	2	3	3
3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	5	5	5	5	5
6	6	6	6	6	6	6	7	7	7
9	9	9	9	9	10	10	10	10	10
10	11	11	11	11	12	12	12	13	13
13	13	13	14	14	14	14	14	14	14
14	16	16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16	16	16
16	17	17	17	17	17	17	17	17	17
17	17	17	17	17	17	17	18	18	18
18	18	18	18	18	18	18	18	18	18
18	18	18	18	18	18	18	18	18	18
18	18	18	18	16	18	19	19	19	19
19	19	19	19	19	19	19	19	19	19
19	19	19	19	19	19	20	20	20	20
20	21	21	21	21	22	22	22	22	22
23	23	25	26	26	29	29	31	31	31
36	36	36	37	39	41	41	43	44	45
56	56	56	58	58	62	63	63	63	63
73	73	73	73	75	77	77	79	79	83
98	100	102	105	108	109	113	114	114	116
135	142	146	146	157	163	165	170	176	163
210	213	213	214	217	217	217	217	217	217
217	217	219	219	219	219	219	221	221	221
221	221	221	221	221	221	221	221	221	221
221	221	221	221	221	221	221	221	221	221
221	221	221	221	219	219	219	219	219	219
219	218	196	192	9					

SERIAL CORRELATION = .734 STANDARD DEVIATION = .254 MEAN SENSITIVITY = .143 N = 284

8KN549 BURNED MOUNTAIN, NEW MEXICO **INDICES**
DOUGLAS-FIR
LATITUDE 36 40 LONGITUDE 106 12 ELEVATION 9800 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

	TREE RING INDICES										NUMBER OF SAMPLES									
DATE	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1718									84	77									1	1
1720	156	100	90	65	80	85	116	59	66	46	1	2	2	2	2	2	2	2	2	2
1730	34	50	68	97	90	109	116	86	106	110	2	2	2	2	2	2	2	2	2	2
1740	106	130	115	125	106	114	103	85	24	71	3	3	3	3	3	3	3	3	3	3
1750	74	80	66	70	120	102	84	73	106	117	3	3	3	3	3	3	3	3	3	4
1760	101	135	125	108	100	127	127	115	105	96	4	4	6	6	6	6	6	6	6	6
1770	85	108	92	72	91	108	89	69	121	113	6	6	6	6	6	6	6	6	7	7
1780	94	96	101	130	119	121	106	125	110	145	12	12	12	12	12	12	13	13	13	13
1790	145	136	126	136	117	68	75	91	91	101	13	13	14	15	15	15	15	15	16	16
1800	107	102	122	109	117	65	59	85	90	84	17	17	17	17	17	17	17	17	17	18
1810	83	89	63	80	75	81	89	80	41	40	18	18	18	18	18	18	18	18	18	18
1820	54	82	50	82	84	91	96	124	148	127	20	20	20	21	21	21	23	23	23	23
1830	125	124	96	92	89	103	77	96	95	109	26	26	26	26	27	27	27	27	27	28
1840	115	97	110	118	115	84	64	53	79	91	26	31	31	31	31	31	31	31	31	31
1850	100	52	77	86	103	118	104	111	110	118	31	31	31	31	31	31	31	31	31	31
1860	143	93	123	115	106	99	156	139	130	139	31	31	31	31	31	31	31	32	32	32
1870	92	85	90	85	84	77	87	94	62	86	32	32	32	32	34	34	36	40	40	42
1880	80	90	108	102	107	112	104	106	98	79	46	46	52	55	57	57	59	65	69	70
1890	65	73	67	58	68	92	77	99	128	74	70	70	70	71	71	76	78	79	79	79
1900	83	81	61	113	72	112	124	174	144	136	84	84	84	84	84	84	84	84	84	84
1910	120	162	170	135	134	113	103	100	90	112	89	89	89	90	90	90	90	90	90	90
1920	100	111	86	92	108	72	99	94	82	88	90	90	90	90	90	90	90	90	90	90
1930	83	63	78	86	42	71	87	111	92	70	90	90	90	90	90	90	90	90	90	90
1940	83	106	99	86	95	79	74	104	106	107	90	90	90	90	90	90	90	90	90	90
1950	101	69	81	79	74	59	52	68	85	81	90	90	90	90	90	90	90	90	90	90
1960	100	97	110	90	98	131	139	116	157	167	90	90	90	90	90	90	90	90	90	90
1970	154	128	118	128	147	127	90	76	124	126	90	90	90	90	90	90	90	90	90	89
1980	117	128	128	132							89	89	56	55						

SERIAL CORRELATION = .657 STANDARD DEVIATION = .256 MEAN SENSITIVITY = .179 N = 206

8MW659 BURNED MOUNTAIN, NEW MEXICO **INDICES**
WHITE FIR
LATITUDE 36 42 LONGITUDE 106 13 ELEVATION 10000 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

	TREE RING INDICES										NUMBER OF SAMPLES									
DATE	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1900	63	89	72	108	88	75	85	100	97	93	1	1	1	1	1	2	2	2	2	2
1910	88	107	87	80	102	96	92	85	99	91	10	11	11	11	11	11	11	12	12	12
1920	82	96	95	103	97	111	101	99	91	94	19	19	19	19	21	21	22	22	22	22
1930	111	49	152	131	99	105	108	102	104	92	24	24	24	27	29	31	34	34	34	34
1940	105	113	88	113	117	101	67	108	100	96	35	35	35	35	36	36	36	37	37	37
1950	90	81	73	69	73	76	51	71	83	87	42	42	42	42	45	45	45	45	45	45
1960	66	86	102	92	91	109	121	129	131	135	45	45	45	45	45	45	45	45	45	45
1970	120	115	117	103	130	110	100	92	102	98	45	45	45	45	45	45	45	45	45	45
1980	93	100	120	118							45	45	45	43						

SERIAL CORRELATION = .617 STANDARD DEVIATION = .169 MEAN SENSITIVITY = .118 N = 84

BMT649 BURNED MOUNTAIN, NEW MEXICO **INDICES**
PONDEROSA PINE
LATITUDE 36 38 LONGITUDE 106 12 ELEVATION 9040 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

TREE RING INDICES

DATE	0	1	2	3	4	5	6	7	8	9
1790	97	91	105	106	99	100	78	100	102	104
1800	103	101	102	105	112	116	117	120	117	117
1810	116	115	90	91	99	96	101	78	40	60
1820	98	94	50	87	97	102	105	127	133	123
1830	127	115	110	113	119	116	102	98	78	106
1840	119	107	103	85	109	94	53	46	59	86
1850	81	42	87	102	116	107	98	112	111	101
1860	132	60	102	114	109	87	119	127	116	138
1870	110	107	118	109	111	106	112	93	62	83
1880	63	83	86	107	104	129	97	108	100	99
1890	81	101	107	84	76	116	74	98	100	71
1900	38	80	54	96	69	83	87	157	138	128
1910	108	133	139	136	158	140	144	98	113	126
1920	103	120	71	91	101	69	96	100	88	104
1930	114	102	111	119	65	109	111	112	104	103
1940	106	132	118	120	81	96	63	92	76	82
1950	76	40	76	69	91	60	56	82	81	58
1960	85	81	105	71	87	117	126	101	116	125
1970	98	90	89	111	127	131	141	100	124	122
1980	108	117	137	126						

NUMBER OF SAMPLES

DATE	0	1	2	3	4	5	6	7	8	9
1790	6	6	7	7	9	10	10	10	10	10
1800	12	12	13	13	14	14	15	15	16	16
1810	17	18	18	18	18	18	18	18	19	19
1820	19	19	19	19	19	19	19	19	19	19
1830	23	24	24	24	24	24	24	24	24	24
1840	24	24	24	24	24	24	24	24	24	24
1850	24	24	24	24	24	24	24	24	24	24
1860	24	24	24	24	24	24	24	24	24	24
1870	24	24	24	24	24	24	24	24	24	24
1880	24	24	24	24	24	24	24	24	24	24
1890	24	24	24	24	24	24	24	24	24	24
1900	22	22	22	22	22	22	22	22	22	22
1910	22	22	22	22	22	22	22	22	22	22
1920	22	22	22	22	22	22	22	22	22	22
1930	22	22	22	22	22	22	22	22	22	22
1940	22	22	22	22	22	22	22	22	22	22
1950	22	22	22	22	22	22	22	22	22	22
1960	22	22	22	22	22	22	22	22	22	22
1970	22	22	22	22	22	22	22	22	22	22
1980	22	22	22	20						

SERIAL CORRELATION = .554 STANDARD DEVIATION = .224 MEAN SENSITIVITY = .179 N = 194

CCN620 CABRESTO CANYON, NEW MEXICO **INDICES**
PINYON
LATITUDE 36 43 LONGITUDE 105 33 ELEVATION 8000 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

DATE	TREE RING INDICES 0	1	2	3	4	5	6	7	8	9	NUMBER OF SAMPLES 0	1	2	3	4	5	6	7	8	9
1592			118	87	117	104	94	72	34	64			1	2	2	2	2	2	2	2
1600	87	55	81	88	68	64	94	82	96	109	2	2	2	2	2	2	2	2	2	2
1610	155	102	143	110	120	127	63	69	138	91	2	2	2	2	2	3	3	3	3	3
1620	145	154	104	106	107	56	118	99	93	154	3	3	3	3	3	3	3	3	3	3
1630	145	61	77	137	85	117	64	103	54	107	3	3	3	3	3	3	3	3	3	3
1640	144	61	109	130	139	56	142	156	77	126	3	3	3	3	3	3	3	3	3	3
1650	117	123	111	113	44	132	77	78	32	100	4	4	4	4	4	4	4	4	4	4
1660	95	80	90	125	90	107	43	78	77	62	4	4	4	4	4	4	4	4	4	4
1670	119	92	128	82	95	41	82	58	89	27	4	4	4	4	4	4	4	4	4	4
1680	99	98	37	128	100	48	109	114	130	135	4	4	4	4	4	4	4	4	4	4
1690	86	105	92	136	113	133	82	104	113	135	4	4	4	4	4	4	4	4	4	4
1700	70	137	100	97	65	72	156	76	101	66	6	6	6	6	6	6	6	6	6	6
1710	172	140	122	117	102	69	83	109	167	58	6	6	6	6	6	6	6	6	6	6
1720	163	88	74	66	82	71	138	70	60	29	6	6	6	6	6	6	6	6	6	6
1730	61	97	124	76	129	56	158	73	66	122	6	6	6	6	6	6	6	7	7	7
1740	96	104	123	149	82	106	154	139	16	111	8	8	8	8	8	8	8	9	9	9
1750	85	142	51	118	155	122	80	106	101	109	10	10	10	10	11	11	11	11	11	11
1760	126	139	135	70	76	59	120	118	146	103	11	11	13	13	13	13	13	13	13	13
1770	111	154	130	80	65	72	84	82	95	58	13	15	15	16	16	16	16	16	16	16
1780	41	67	92	112	162	66.	61	136	114	60	16	16	16	16	16	16	16	16	16	16
1790	121	137	115	91	81	64	68	67	99	114	16	16	16	16	16	16	16	16	16	16
1800	125	53	112	150	138	86	96	110	81	36	16	17	17	16	16	16	18	18	18	18
1810	105	69	93	101	58	104	136	105	45	31	16	18	18	18	16	18	16	18	18	16
1820	43	97	59	78	85	98	134	142	180	113	18	16	16	16	16	16	18	18	18	18
1830	148	100	97	72	73	103	74	119	107	137	16	18	18	16	18	18	18	18	18	18
1840	104	120	55	75	118	89	52	43	71	134	18	18	18	16	16	18	18	18	18	18
1850	122	15	111	138	108	84	105	81	138	123	16	16	16	16	16	16	18	18	18	16
1860	120	29	119	94	64	85	148	154	140	166	18	18	16	16	16	16	16	18	16	18
1870	55	94	137	5	95	110	122	87	139	96	16	18	16	18	16	16	16	18	16	18
1880	87	162	137	82	156	153	113	144	117	104	18	18	16	16	16	18	16	18	16	18
1890	94	151	137	63	69	141	101	115	144	25	19	19	19	19	19	19	19	19	19	19
1900	86	93	50	164	41	137	84	118	124	97	20	20	20	20	20	20	20	20	20	20
1910	98	148	152	73	156	156	100	113	104	149	20	20	20	20	20	20	20	20	20	20
1920	159	164	94	50	126	91	99	105	95	84	20	20	20	20	20	20	20	20	20	20
1930	98	102	130	69	120	110	59	117	114	73	20	20	20	20	20	20	20	20	20	20
1940	83	130	117	74	127	111	17	107	67	110	20	20	20	20	20	20	20	20	20	20
1950	79	55	51	77	103	115	12	108	97	103	20	19	19	19	19	19	19	19	19	19
1960	94	73	42	75	28	117	102	60	76	75	16	16	16	16	16	18	18	18	18	18
1970	97	63	121	117	59	119	74	84	112	144	16	16	18	16	18	18	18	18	18	18
1980	129	129									17	15								

SERIAL CORRELATION = .081 STANDARD DEVIATION = .329 MEAN SENSITIVITY = .385 N = 340

CAB549 CABRESTO CANYON, NEW MEXICO **INDICES**
DOUGLAS-FIR
LATITUDE 36 43 LONGITUDE 105 33 ELEVATION 7900 FEET
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

DATE	TREE RING INDICES 0	1	2	3	4	5	6	7	8	9	NUMBER OF SAMPLES 0	1	2	3	4	5	6	7	8	9
1671		93	101	45	71	65	111	105	86	74		1	1	2	2	3	3	3	4	4
1680	53	92	107	76	98	114	66	111	113	91	4	4	5	5	6	8	8	8	8	8
1690	66	126	119	74	51	105	72	86	121	65	12	12	12	14	14	14	14	14	14	14
1900	78	73	60	121	70	100	105	135	116	80	14	14	14	14	14	14	14	14	14	14
1910	79	124	140	76	113	124	123	128	105	134	16	18	16	16	16	16	18	18	16	18
1920	121	155	105	66	102	83	120	134	126	121	16	18	18	16	16	18	16	18	16	18
1930	115	109	124	137	106	111	97	121	113	70	16	16	18	16	18	16	16	16	18	18
1940	74	123	116	70	127	119	50	125	102	125	16	18	18	16	18	16	16	16	18	18
1950	65	51	72	60	78	114	34	97	105	60	16	18	18	16	18	18	16	16	18	18
1960	104	81	39	52	55	127	106	63	96	99	16	16	16	18	16	18	18	18	18	18
1970	125	30	128	126	89	133	96	84	137	163	16	16	16	16	16	16	18	18	18	18
1980	158	111									18	18								

SERIAL CORRELATION = .214 STANDARD DEVIATION = .278 MEAN SENSITIVITY = .303 N = 111

APPENDIX B

Corrected Tree-ring Indices

CPNALL CAPULIN CANYON, NEW MEXICO **CORRECTED INDICES**
DOUGLAS-FIR
LATITUDE 36 25 LONGITUDE 105 22 ELEVATION 2895 METERS
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

TREE RING INDICES

DATE	0	1	2	3	4	5	6	7	8	9
1790	151	128	109	89	57	78	95	77	99	95
1800	100	111	121	129	116	106	77	119	107	87
1810	83	98	158	136	106	109	115	116	102	93
1820	76	116	107	109	91	102	76	93	92	72
1830	90	92	111	111	104	106	98	130	145	106
1840	105	91	90	160	127	94	92	75	100	80
1850	100	93	99	70	71	92	113	89	64	82
1860	64	77	81	75	88	93	85	102	102	105
1870	90	101	85	91	101	68	92	105	101	104
1880	106	102	127	123	131	123	117	115	110	98
1890	90	108	90	94	73	73	81	88	75	98
1900	118	98	87	87	93	105	104	90	87	94
1910	97	116	133	95	90	99	87	112	101	122
1920	117	112	118	95	103	98	125	102	112	123
1930	130	127	138	160	107	101	114	101	83	83
1940	69	86	67	59	40	65	76	98	93	89
1950	82	103	99	118	74	115	107	115	126	90
1960	80	62	62	92	79	79	66	102	101	76
1970	112	112	127	128	118	143	120	97	87	113
1980	112	48								

NUMBER OF SAMPLES

0	1	2	3	4	5	6	7	8	9
2	2	2	2	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	6	6	6
6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	7	7	8	8	8
9	9	10	10	10	10	12	14	14	14
14	14	14	14	14	14	14	14	14	14
14	14	14	14	14	14	14	14	17	17
17	18	18	18	20	20	20	20	20	20
20	20	28	28	28	28	28	28	30	30
34	34	34	36	36	38	38	39	41	43
51	51	51	51	51	51	51	52	52	52
58	60	61	62	64	67	68	70	70	79
85	87	89	91	91	95	98	99	101	105
109	109	111	111	113	113	113	113	113	113
113	113	113	113	113	113	113	113	113	113
113	113	113	113	113	113	113	113	113	113
111	103								

CPU650 CAPULIN CANYON, NEW MEXICO **CORRECTED INDICES**
WHITE FIR
LATITUDE 36 25 LONGITUDE 105 30 ELEVATION 2895 METERS
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

TREE RING INDICES

DATE	0	1	2	3	4	5	6	7	8	9
1838									91	58
1840	108	97	96	116	73	76	78	86	103	78
1850	126	99	141	68	80	77	74	72	83	66
1860	62	90	71	82	113	111	127	109	112	122
1870	91	94	83	107	98	92	94	113	99	106
1880	96	101	127	113	135	133	132	124	101	94
1890	94	128	100	93	87	69	67	87	71	91
1900	120	94	101	104	101	127	109	92	86	123
1910	101	131	140	118	118	111	85	113	98	112
1920	129	122	123	110	117	109	135	102	112	123
1930	115	130	152	155	114	105	110	97	74	78
1940	58	57	51	49	39	59	67	76	73	70
1950	68	90	96	119	84	133	117	125	127	91
1960	78	57	54	71	61	52	37	76	76	70
1970	113	103	114	145	132	137	108	99	84	135
1980	142	84								

NUMBER OF SAMPLES

0	1	2	3	4	5	6	7	8	9
								1	1
2	2	2	2	2	2	2	2	2	2
2	2	4	4	4	4	4	5	6	7
8	8	8	8	8	8	8	8	8	8
12	12	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12
12	12	12	12	13	13	13	13	13	13
13	14	14	14	14	14	14	14	14	14
16	16	19	19	22	23	24	28	28	28
29	29	29	30	31	31	31	32	32	32
32	32	33	34	34	36	36	36	36	36
36	36	37	37	37	42	43	43	43	46
50	50	50	50	50	50	50	50	50	50
50	50	50	50	50	50	50	50	50	50
50	50	50	50	50	50	50	50	50	50
49	49								

GAR549 GARCIA PARK, NEW MEXICO **CORRECTED INDICES**
DOUGLAS-FIR
LATITUDE 36 20 LONGITUDE 105 23 ELEVATION 2877 METERS
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

TREE RING INDICES

DATE	0	1	2	3	4	5	6	7	8	9
1700	67	31	75	69	112	101	156	142	123	109
1710	136	126	131	132	117	117	131	147	139	118
1720	94	137	132	102	93	109	100	108	150	118
1730	114	152	147	117	143	131	144	116	169	122
1740	101	108	83	122	107	93	102	108	109	98
1750	88	99	103	120	97	106	83	92	85	90
1760	73	92	72	49	64	89	75	83	75	61
1770	86	95	64	91	86	88	96	105	99	98
1780	101	101	126	113	126	124	98	91	97	91
1790	129	136	103	107	88	83	66	66	82	74
1800	99	98	90	87	72	68	63	75	76	78
1810	73	80	93	88	82	107	119	110	73	97
1820	77	104	100	114	83	99	96	82	96	61
1830	109	105	93	64	90	87	79	98	119	107
1840	81	89	113	144	124	92	112	102	124	95
1850	117	98	130	101	100	124	119	109	101	107
1860	99	119	123	113	135	101	85	76	76	103
1870	61	106	100	91	95	60	90	98	86	82
1880	104	104	100	107	132	95	86	71	86	75
1890	86	124	103	73	71	41	74	43	55	74
1900	110	93	109	87	89	58	96	98	96	117
1910	106	125	143	124	116	126	89	128	116	157
1920	134	134	119	108	109	97	121	114	100	88
1930	105	117	121	162	115	110	118	95	87	71
1940	85	63	71	69	68	53	99	81	94	84
1950	86	106	79	104	109	140	149	136	145	137
1960	99	88	65	96	53	57	75	111	107	84
1970	131	149	160	132	117	97	79	89	103	109
1980	45	20								

NUMBER OF SAMPLES

DATE	0	1	2	3	4	5	6	7	8	9
1700	2	2	2	2	2	2	2	3	3	3
1710	5	6	6	6	6	6	6	6	6	6
1720	6	7	7	7	7	7	7	7	7	7
1730	8	8	8	8	8	8	8	8	8	8
1740	11	11	11	11	11	11	11	11	11	11
1750	13	13	13	13	13	13	13	13	13	13
1760	16	16	17	17	17	17	17	17	17	17
1770	21	21	22	25	25	25	25	25	25	25
1780	26	26	26	26	26	26	26	26	26	26
1790	28	28	29	30	30	31	31	31	31	31
1800	32	33	33	33	33	33	33	33	33	33
1810	33	33	33	33	33	33	33	33	34	34
1820	34	34	35	36	36	37	37	37	38	38
1830	41	41	42	43	43	43	43	44	44	44
1840	52	52	52	52	52	52	52	52	52	52
1850	59	59	59	59	59	59	59	59	59	59
1860	65	65	65	67	67	67	67	67	67	67
1870	71	71	71	71	71	71	71	71	71	71
1880	72	72	72	72	72	72	72	72	72	72
1890	77	77	78	78	78	78	78	78	78	78
1900	79	79	79	79	79	79	79	79	79	79
1910	87	87	87	87	87	87	87	87	87	87
1920	88	88	89	89	89	89	89	89	89	89
1930	91	91	91	91	91	91	91	91	91	91
1940	91	91	91	91	91	91	91	91	91	91
1950	91	91	91	91	91	91	91	91	91	91
1960	91	91	91	91	91	91	91	90	89	89
1970	90	90	90	90	90	90	90	89	89	87
1980	81	80								

OSHALL OSHA MOUNTAIN, NEW MEXICO **CORRECTED INDICES**
DOUGLAS-FIR
LATITUDE 36 40 LONGITUDE 105 25 ELEVATION 3048 METERS
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

TREE RING INDICES

DATE	0	1	2	3	4	5	6	7	8	9
1700	161	131	128	144	175	94	94	128	103	101
1710	98	104	141	109	93	97	63	67	38	71
1720	68	91	102	87	94	66	88	86	100	112
1730	89	103	107	101	107	110	102	115	110	121
1740	115	110	100	124	110	94	90	92	110	69
1750	104	104	115	130	140	117	108	98	106	92
1760	68	61	78	65	80	83	90	95	92	99
1770	87	96	98	97	91	96	96	92	93	90
1780	109	108	114	113	94	104	98	103	109	107
1790	140	119	106	97	99	95	104	111	113	113
1800	96	126	140	129	116	94	44	75	79	87
1810	83	66	85	79	67	63	99	92	80	73
1820	60	75	65	91	88	79	95	106	96	107
1830	110	105	111	106	94	112	106	111	104	112
1840	92	91	107	137	124	108	116	113	121	123
1850	132	114	131	101	93	91	103	73	87	99
1860	87	85	106	89	98	92	78	79	78	85
1870	75	93	67	84	83	94	87	88	94	93
1880	121	115	110	111	110	98	99	110	101	91
1890	77	91	97	80	101	89	67	79	71	75
1900	76	67	67	76	91	82	92	79	80	99
1910	92	117	129	100	73	81	64	110	96	114
1920	108	90	100	89	98	107	103	111	113	112
1930	127	124	127	130	107	100	114	118	105	91
1940	82	78	69	51	78	66	83	103	107	108
1950	97	87	89	125	114	130	130	115	105	86
1960	74	78	69	85	100	91	76	66	81	78
1970	108	131	131	116	118	132	126	116	127	137
1980	115	90								

NUMBER OF SAMPLES

DATE	0	1	2	3	4	5	6	7	8	9
1700	1	1	1	1	2	2	2	2	3	3
1710	3	3	3	3	3	3	3	3	3	3
1720	4	4	4	4	4	5	5	5	5	5
1730	6	6	6	6	6	6	6	7	7	7
1740	9	9	9	9	9	10	10	10	10	10
1750	10	11	11	11	11	12	12	12	13	13
1760	13	13	13	14	14	14	14	14	14	14
1770	14	16	16	16	16	16	16	16	16	16
1780	16	16	16	16	16	16	16	16	16	16
1790	16	17	17	17	17	17	17	17	17	17
1800	17	17	17	17	17	17	17	18	18	18
1810	18	18	18	18	18	18	18	18	18	18
1820	18	18	18	18	18	18	18	18	18	18
1830	18	18	18	18	18	18	19	19	19	19
1840	19	19	19	19	19	19	19	19	19	19
1850	19	19	19	19	19	19	20	20	20	20
1860	20	21	21	21	21	22	22	22	22	22
1870	23	23	25	26	26	29	29	31	31	31
1880	36	36	36	37	39	41	41	43	44	45
1890	56	56	56	58	58	62	63	63	63	63
1900	73	73	73	73	75	77	77	79	79	83
1910	98	100	102	105	108	109	113	114	114	116
1920	135	142	146	148	157	163	165	170	178	183
1930	210	213	213	214	217	217	217	217	217	217
1940	217	217	219	219	219	219	219	221	221	221
1950	221	221	221	221	221	221	221	221	221	221
1960	221	221	221	221	221	221	221	221	221	221
1970	221	221	221	221	219	219	219	219	219	219
1980	219	218								

BRN549 BURNED MOUNTAIN, NEW MEXICO **CORRECTED INDICES**
DOUGLAS-FIR
LATITUDE 36 40 LONGITUDE 106 12 ELEVATION 2960 METERS
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

TREE RING INDICES

DATE	0	1	2	3	4	5	6	7	8	9
1790	148	146	120	129	117	88	100	90	90	97
1800	103	101	120	103	104	67	39	62	71	63
1810	65	72	74	91	77	86	88	105	111	86
1820	56	89	106	97	88	89	90	94	110	101
1830	93	106	65	78	68	65	74	99	121	102
1840	93	89	107	136	105	92	119	116	127	108
1850	123	119	91	84	84	110	106	97	97	117
1860	106	139	121	98	96	115	135	108	110	96
1870	80	76	69	75	71	70	73	102	125	106
1880	123	109	122	93	102	79	107	96	99	80
1890	87	73	60	77	95	74	106	102	128	108
1900	155	104	114	117	107	131	139	108	100	104
1910	112	124	125	94	67	66	52	102	74	82
1920	97	88	120	102	106	85	104	94	96	64
1930	67	61	65	64	83	60	75	97	88	67
1940	76	69	78	63	116	84	117	114	131	126
1950	128	138	109	115	84	106	103	89	107	129
1960	118	119	105	124	113	111	109	115	139	138
1970	156	140	132	116	115	90	43	76	96	100
1980	108	109	85	102						

NUMBER OF SAMPLES

DATE	0	1	2	3	4	5	6	7	8	9
1790	13	13	14	15	15	15	15	15	16	16
1800	17	17	17	17	17	17	17	17	17	18
1810	18	18	18	18	18	18	18	18	16	18
1820	20	20	20	21	21	21	23	23	23	23
1830	26	26	26	26	27	27	27	27	27	28
1840	28	31	31	31	31	31	31	31	31	31
1850	31	31	31	31	31	31	31	31	31	31
1860	31	31	31	31	31	31	31	32	32	32
1870	32	32	32	32	34	34	36	40	40	42
1880	46	46	52	55	57	57	59	65	69	70
1890	70	70	70	71	71	76	78	79	79	79
1900	84	84	84	84	84	84	84	84	84	64
1910	89	89	89	90	90	90	90	90	90	90
1920	90	90	90	90	90	90	90	90	90	90
1930	90	90	90	90	90	90	90	90	90	90
1940	90	90	90	90	90	90	90	90	90	90
1950	90	90	90	90	90	90	90	90	90	90
1960	90	90	90	90	90	90	90	90	90	90
1970	90	90	90	90	90	90	90	90	90	89
1980	89	89	56	55						

BMW659 BURNED MOUNTAIN, NEW MEXICO **CORRECTED INDICES**
WHITE FIR
LATITUDE 36 42 LONGITUDE 106 13 ELEVATION 3048 METERS
COLLECTED BY T. W. SWETNAM, T. P. HARLAN, E. K. SUTHERLAND

TREE RING INDICES

DATE	0	1	2	3	4	5	6	7	8	9
1900	105	103	103	111	109	87	95	64	73	76
1910	64	86	63	58	65	71	65	87	91	75
1920	81	84	116	110	98	120	104	100	100	92
1930	103	99	146	120	123	100	103	95	103	91
1940	102	93	78	101	130	105	113	114	115	109
1950	107	121	90	91	80	105	81	84	96	115
1960	99	100	100	112	100	98	105	129	122	120
1970	123	123	126	97	113	90	75	93	88	84
1980	89	90	97	102						

NUMBER OF SAMPLES

DATE	0	1	2	3	4	5	6	7	8	9
1900	1	1	1	1	1	2	2	2	2	2
1910	10	11	11	11	11	11	11	12	12	12
1920	19	19	19	19	21	21	22	22	22	22
1930	24	24	24	27	29	31	34	34	34	34
1940	35	35	35	35	36	36	36	37	37	37
1950	42	42	42	42	45	45	45	45	45	45
1960	45	45	45	45	45	45	45	45	45	45
1970	45	45	45	45	45	45	45	45	45	45
1980	45	45	45	43						

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